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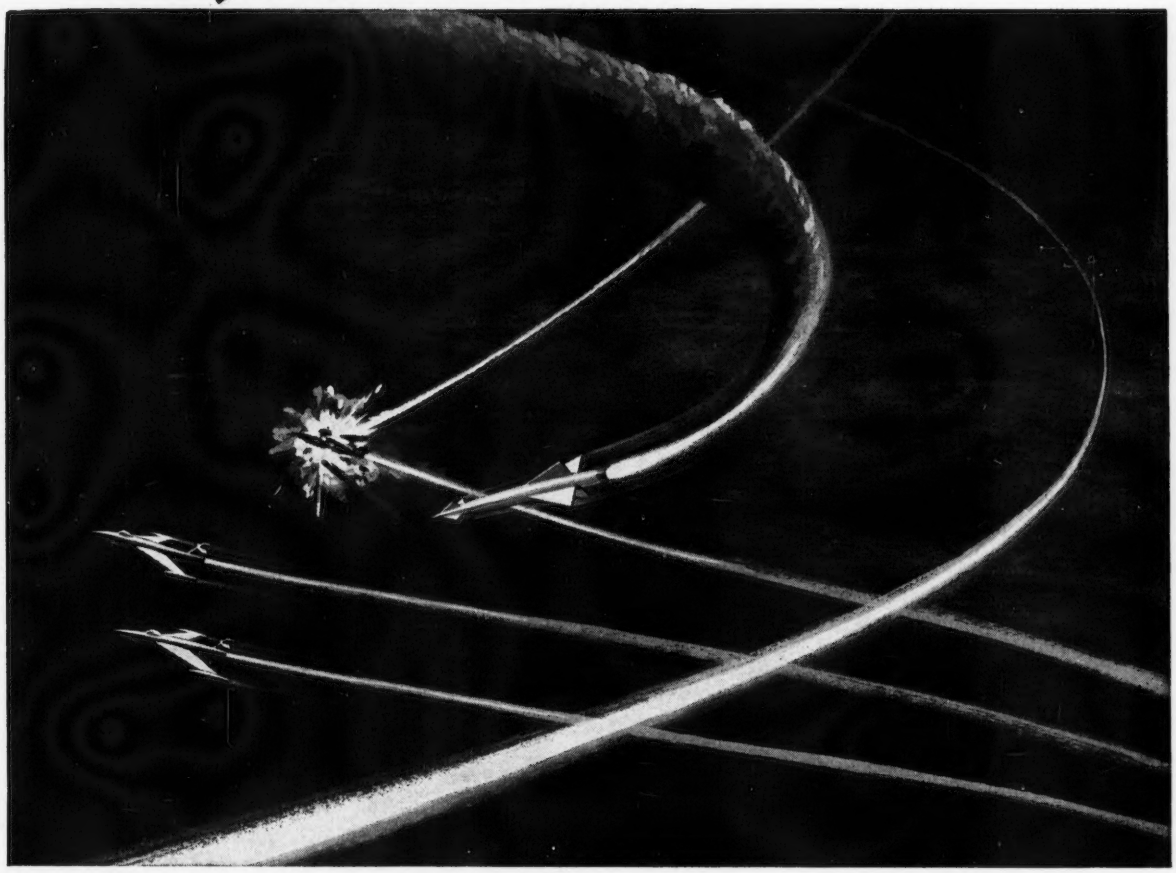
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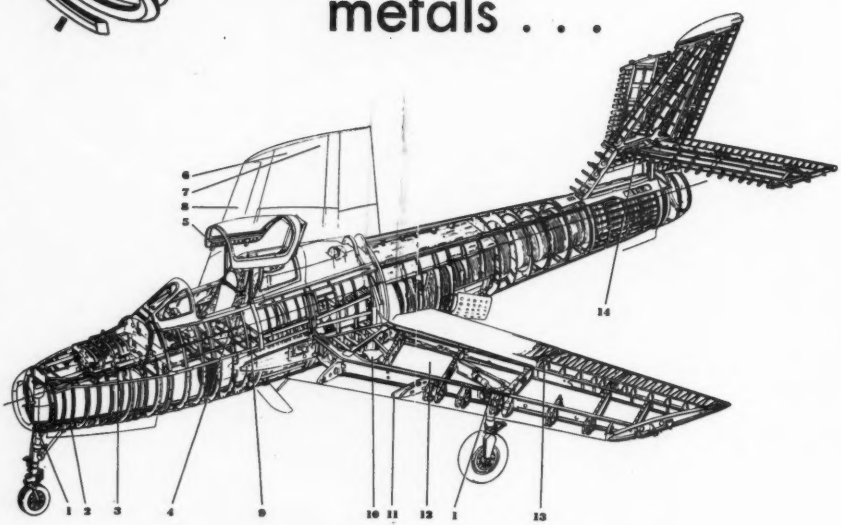
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THE RUNWAY BARRIER



National Defence Photo

A CF-100 Mk 4 engages the Runway Barrier in a simulated over-shoot during RCAF Barrier Trials at Uplands. **(See Page 162)**

EDITORIAL

AWARDS

Probably every society, or community of people, has adopted the practice of giving awards to those who have made important contributions to the interests of its members. Awards have varied from laurel wreaths to prizes of substantial intrinsic value, but the size of an award has seldom been so significant as the awarding of it. In making the award the society has publicly recognized the effort of the individual and it is in this recognition that the recipient finds his real satisfaction.

In another form of recognition, great men have been honoured by their contemporaries by the establishment of memorials, whereby their names and achievements might be recognized by succeeding generations.

Societies such as ours, devoted to the advancement of particular arts and sciences, have long followed the rather happy practice of combining their memorials to past achievements with their awards for more recent achievements, and they have set up prizes, scholarships, medals and trophies, named after men who have made noteworthy contributions in the past and presented periodically to those whose more recent contributions are worthy of recognition. An interesting form of these "memorial-awards" is the memorial lecture, delivered by some eminent man to a special meeting of the sponsoring society. The chosen lecturer receives a premium, but his chief honour lies in being invited to deliver the lecture; it is no ordinary lecture, and he knows that he has been very carefully selected for it.

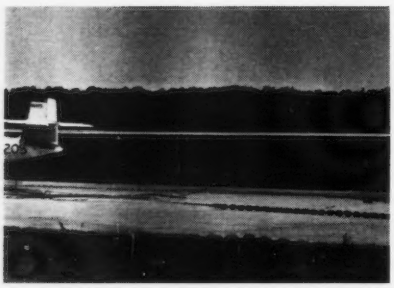
In all awards it is, of course, of great importance that the winners should be selected carefully and impartially. Nowadays aeronautical work has become so extensive and complex that a complete accomplishment or an invention is seldom attributable to any one individual, and almost every worthwhile contribution is made by a group or team of workers. Consequently it is not unreasonable, in some cases, to make awards to the leaders of such teams on behalf of the men for whose work they are responsible. Unfortunately no one seems to have been able to do this in such a way that the members of the teams are always happy about it, and this form of award, though obviously justifiable, is often misunderstood and unpopular. The problem of selection is therefore not an easy one. In our Institute, selection is made by the full Council, guided by a Committee which does the preliminary screening of the nominations.

The Canadian Aeronautical Institute administers two awards at present, namely the "McCurdy Award" and the "W. Rupert Turnbull Lecture". The former was originated by the Institute of Aircraft Technicians to commemorate the work of the Hon. J. A. D. McCurdy, the first British subject to fly in the British Empire, and to recognize annually outstanding achievement in design, manufacture or maintenance related to aeronautics, by a resident of Canada. It was first awarded in 1954, as a last act of the I.A.T. before merging into the C.A.I., and its trophy and silver medal were presented by Mr. McCurdy in person at the Annual General Meetings of the C.A.I. in 1954 and 1955.

The W. Rupert Turnbull Lecture was established in 1955 as a memorial to the late Dr. Turnbull, pioneer aeronautical engineer and father of the variable-pitch propeller; the Lecturer receives a certificate and a special premium. The inaugural Lecture of the series was read to the International Meeting of the I.A.S. and C.A.I. on the 3rd November 1955.

In time, as occasions arise and as the necessary endowment funds become available, the Institute will no doubt add to its awards for the recognition of good work and the encouragement of further endeavour. These aims are implicit in the stated objects of the Institute and it is most right and proper that their fulfilment should serve to commemorate the work and endeavour of earlier years.

CF-100 RUNWAY BARRIER TRIALS





National Defence Photo

UNTIL such time as the VTO aircraft or the convertaplane become fully operational, the landing problems of aerodynamically clean aeroplanes and high wing loadings must be faced. A consequence of both these problems is the necessity of long runways; but even the 8000 foot strips are inadequate for a clean aeroplane with faulty brakes, or during an aborted take-off.

The RCAF in cooperation with the USAF, has been conducting experiments with a device that is intended to arrest the run-away aircraft within a short distance, and while doing so, to cause a minimum of damage to the aircraft, and to save the lives of the occupants.

The runway barrier was first conceived in Korea by the USAF where jet fighters were operating out of short fields, and constantly faced with the hazards of landing crippled aircraft, or taking-off with full operational load in varying weather and runway conditions.

Following its early successes, the USAF proceeded with further refinements in Japan, and subsequently commenced full scale development trials in the USA. The object of the more recent experiments has been to develop an arrestor capable of stopping any type of jet aircraft with a minimum elapsed time for resetting the barrier.

The RCAF interest was aroused through the problems encountered by Air Defence Command during its winter operations of all-weather fighters. Landing on ice or snow-covered runways represents an additional intricacy to high landing speeds, and accordingly it was decided to investigate the potentialities of the USAF barrier.

The barrier consists of three main assemblies: a triggering mechanism which is actuated by the nose oleo leg; the arresting gear which engages with the main oleo legs, and a remote control which enables the control tower to raise or lower the barrier with a maximum of six seconds response time.

The triggering is achieved by a nylon webbing assembly which is stretched between two stanchions, one on each side of the runway, and located at the end of the runway hardtop, at the start of the 1000 foot gravel overshoot area. The webbing consists of a horizontal adaptor, which is approximately 2½ feet above the runway, from which hang a number of nylon risers about 4½ feet apart. The risers are fastened to pins embedded in, and flush with the runway surface, and are designed to hold the arresting cable about 18 inches from each anchor pin on the upstream side of the pins.

The arresting assembly consists of the arresting cable, lying on the runway, threaded through each riser strap, and the cable ends are fastened to masses of ship type anchor chain, stretched on each side of the overshoot strip downstream from the webbing adaptor for approximately 400 to 500 feet.

Upon contact with the barrier the aircraft nose oleo engages the horizontal webbing adaptor causing each vertical riser to be stretched between its anchor point and the horizontal adaptor. During the inital contact the nose wheel runs over the arresting cable and as the vertical risers stretch the cable is lifted off the runway surface behind the nose wheel. Further stretching of the risers causes the riser loops to open, thus releasing the arresting cable. The cable travels upward and slightly forward, but due to the aircraft motion, it strikes the underside of the fuselage in the vicinity of the main oleo legs and eventually bears against the main legs. As the cable is being loaded, the nylon webbing shears its end fittings and remains draped around the nose oleo leg. An initial tension of the arresting cable is achieved by steel pendants attached to the cable ends and the bottom of the appropriate stanchion. When the cable load reaches 6000 lb. the pendants release and the cable picks up the chain, a link at a time, directing it toward the centre line of the overshoot strip, and streaming it behind the aircraft. Ultimately the friction work of the chain arrests the aircraft within the confines of the overshoot area.

The arresting distance is a function of aircraft weight and engaging velocity for a given mass of chain, and although considerable experimental work has been done by the USAF, very little work has been done with aircraft weights of the order of the CF-100. As a consequence, the RCAF is concentrating its trials on obtaining the best chain configuration that will provide minimum arresting distances with negligible loads on the aircraft.

Ultimately it is hoped that the energy absorption will be achieved by mechanical or electro-mechanical means, thus eliminating the lengthy and difficult task of replacing the chain in preparation for the next arrestment.

Meanwhile the barrier is becoming a standard piece of aircraft installations equipment throughout the military airfields of the world, and is causing many a procurement officer to ponder the provisioning aspects of thousands of tons of anchor chain.

F/L W. M. MCLEISH,
C.E.P.E. Rockcliffe

NUCLEAR PROPULSION, AVIATION'S FUTURE†

by Dr. D. G. Samaras*

Ohio State University

SUMMARY

1. Great advances in transportation have been handicapped by the ignorance of either the existence of powerful sources of energy, or methods for harnessing them.

2. The introduction of nuclear energy sources is expected to be applied to known types of propulsion systems; however, in order to obtain maximum performance, new types of propulsion systems should be invented.

3. Future aviation may be subdivided into the following regions:

a. Terrestrial Aviation;

b. Interplanetary or Solar Aviation;

c. Intragalactic Aviation.

4. Terrestrial aviation was achieved in 1903 by the development of the internal combustion engine together with liquid hydro-carbon fuel.

5. Interplanetary aviation may be attained by the utilization of a nuclear propulsion system; jet propulsion seems satisfactory.

6. Intragalactic aviation seems unlikely to be accomplished by known methods of propulsion; however, more advanced methods, such as field interaction propulsion, may give satisfactory results.

SCIENCE OF PROPULSION

LIFE is mostly identified with *motion*. More than ninety-five per cent of human activities are directly or indirectly associated with motion and transport.

The phenomena associated with transport are examined by the sciences of transportation; *propulsion* may be considered as the pre-eminent among these sciences.

Only during the last century have important advances in transportation been attained. These, although modest at first, today can be considered as the first links of an explosive-like chain reaction. As the scenery of the world and civilization has been changed profoundly by the initial, and rather spectacular, success of the modern science of propulsion, it is worthwhile examining the present situation from this point of view.

It is recognized today that the progress of science appears to be advancing in two main and diverse directions. The first is toward the discovery of new facts. This unceasing search is continually uncovering new facts, which are sometimes inexplicable in the old frames of reference. The second is toward the discovery of new, more general and more realistic frames of reference. When a new frame of reference has been formulated, its effectiveness is always demonstrated by the discovery of new facts at an accelerated pace.

The continuous discovery of new facts in the past dictated the modification and even rejection of accepted axioms, or frames of reference, with constant replacement of old ideas and concepts by new and more exact ones.

The above reasons suggested the necessity of modification in the subdivision and classification of sciences, along with the introduction of new ones.

The classical Aristotelian subdivision and classification of sciences was based on archaic and mediaeval concepts as well as ignorance of modern facts and needs. Under these circumstances a more general, factual and logical frame of reference for the classification of natural sciences was recently advanced[1], namely:

"*Life*"–"*Animation*"–"*Inertia*"

According to this criterion:

a) Knowledge dealing with living objects is covered by the "life" sciences;

b) Knowledge dealing with animated objects is covered by the "animated" sciences;

c) Knowledge dealing with inert objects is covered by the "inert" sciences.

The first group includes all biological sciences, the second group comprises all transportation sciences and the third group contains all inert and otherwise basic sciences.

It should be mentioned here that the vehicle-propulsion system, with its sensing devices, automatic controls and servomechanisms, bears a close resemblance to a living organism. The new classification points out clearly the close relationship between the life (biological) and animated (propulsion) sciences.

HISTORY OF PROPULSION

Scientific forecast is always based on logical and systematic extrapolation into the future. Under these circumstances, the establishment of certain points from the past and present, in the most fruitful system of coordinates, is necessary. Such a system necessarily will contain as one coordinate, *time*, the other one being *speed*. Speed has been accepted in the past to be the most important figure of merit characterizing transportation; consequently, the excellence of performance of a propulsion system may be characterized by vehicle speed.

According to the above, Figure 1 has been prepared, showing the trend in vehicle speed. If the fuel is taken as

†Paper read before the Ottawa and Toronto Branches of the C.A.I. on the 6th and 7th September, 1955 respectively.

*Professor Nuclear Propulsion: Consultant U.S.A.F.

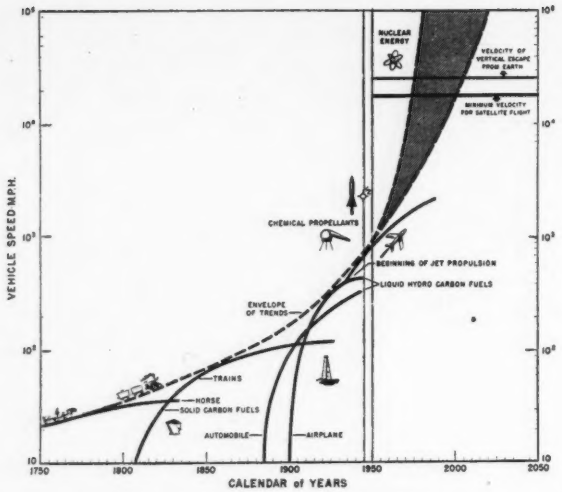


Figure 1. Speed trend in propulsion.

the criterion of sub-division, then the following three periods may distinguish themselves:

a) The first period, during which the power was mostly derived from animals and the fuel used was mostly a carbohydrate;

b) The second period, during which chemical fuels, mostly of the hydrocarbon variety, were used. This period may be subdivided into two subperiods:

(1) Solid hydrocarbons

(2) Liquid hydrocarbons

c) The third period, during which it is expected to utilize nuclear fuels.

From the above picture, it may be seen that the speed trend follows a line similar to a chain reaction, which, combined with realistic guesses on future capabilities, suggests great promise for future progress. The largest figure of merit, vehicle speed, corresponds to aviation; consequently, we will restrict our attention to this most excellent mode of transportation.

Aviation is the most modern and most promising mode of transportation; it has been hardly half a century since its inauguration by the Wright brothers. If the propulsion system is taken as the criterion of subdivision, then Figure 2 shows in a graphical form, the history of aviation.

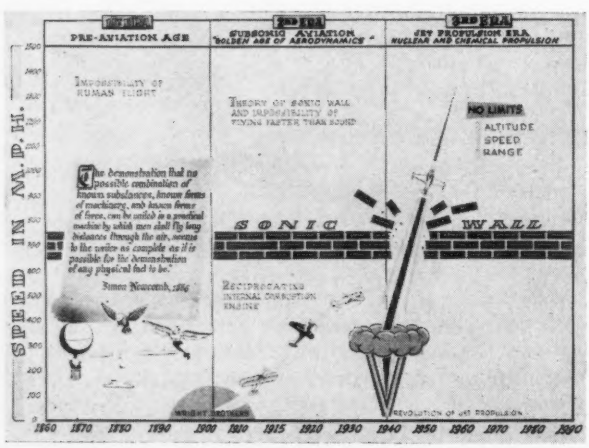


Figure 2. History of aviation.

ENERGY FOR PROPULSION

In the past, aviation was based upon lifting and transporting useful loads. The methods used to produce lift were the following:

a) Static methods, utilizing Archimedean buoyancy in the earth's gravitational field;

b) Dynamic methods, utilizing forces produced by the motion of a fluid. Figure 3 shows the three common dynamic methods of producing lifting forces:

(1) Wing Lift: In this case the propulsive thrust is smaller than the apparent weight of the aircraft.

(2) Thrust Lift: In this case the propulsive thrust is larger than the apparent weight of the aircraft.

(3) Centrifugal Lift: In this case the speed of the vehicle is so large that the centrifugal force counteracts a part or even the whole of the aircraft weight.

The first group corresponds to relatively low-power propulsion systems installed in vehicles flying at low altitudes and speeds. The second and third correspond to more powerful propulsion systems which are installed in aircraft flying at high altitudes and speeds.

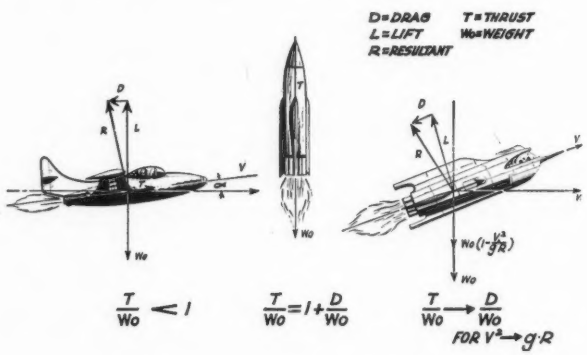


Figure 3. Dynamic methods of aircraft lift.

For the operation of a propulsion system, an energy source is always required. It is felt that it is not an understatement to say that there is an abundance of energy available in nature which may be harnessed for propulsion purposes. In the past, the main handicap toward its exploitation was either ignorance of its existance or ignorance of suitable methods for harnessing it.

It is worthwhile mentioning a few historical examples:

a) Fire (combustion) has been known to man for more than five hundred centuries; however, it has been hardly more than one century since man invented methods of harnessing the Promethean-stolen fire from Olympus into a propulsion system;

b) Electricity has been known to man for nearly twenty-five centuries (Thales of Miletos); however, less than one century has passed since man invented methods of harnessing Zeus' thunderbolts into a propulsion system.

c) It has been hardly a quarter of a century since man recognized and started understanding nuclear energy; however, he has not used it as yet in a propulsion

system, although he has succeeded in harnessing it for power in a rather primitive way.

The conclusions from the above are that today we may not be aware of all energy fields available to us in nature and furthermore, we are desperately ignorant of methods of harnessing the known energy fields.

Existing knowledge suggests that the most important energy sources available today are:

a) Extra-nuclear energy (chemical), which may be released by rearrangements of atomic electrons in the electron cloud surrounding the nucleus;

b) Nuclear energy, which is released by drastic changes in the structure of the atomic nucleus.

All these changes are in satisfactory agreement with the Einstein principle of "mass energy equivalence".

A comparison of the gravimetric energy concentration for the combustion of the elements and their hydrides is shown in Figures 4 and 5. In the same figures are also indicated the gravimetric energy concentration of a few typical fission and fusion nuclear reactions. From the figures, it may be deduced that the gravimetric energy concentration in nuclear reactions is 10^6 to 10^7 times larger than that corresponding to extra-nuclear (chemical) reactions.

Table 1 shows the relative order of magnitudes of gravimetric energy concentration and specific impulse.

TABLE 1

EXTRA-NUCLEAR AND NUCLEAR PERFORMANCE DATA

Energy Type	Gravimetric Energy Concentration (Cal/gm)	Specific Impulse (Sec.)
Extra-Nuclear	10^4	10^2
Nuclear Fission	10^{10}	10^6
Nuclear Fusion	10^{11}	10^7
Mass Annihilation	10^{13}	10^8

As the extra-nuclear energy is so small we shall restrict our attention to the nuclear energy.

NUCLEAR ENERGY APPLICATIONS

Today the following applications of nuclear energy in propulsion systems may be visualized:

a) Terrestrial Aviation;
b) Solar (interplanetary) Aviation;
c) Intragalactic Aviation.

Terrestrial Aviation

Application of a new energy source starts always with more or less conventional and time-proven configurations of propulsion systems. This phenomenon may be explained by the fact that, while science advances in discrete discontinuities (quantum-like levels), technology is desperately trying to follow a somehow continuous rate of progress. Unfortunately this is not the best method of exploitation of a new energy source. This point may be illustrated by the following historical example: The application of liquid hydrocarbon fuels, when used as a substitute for a solid fuel in a steam

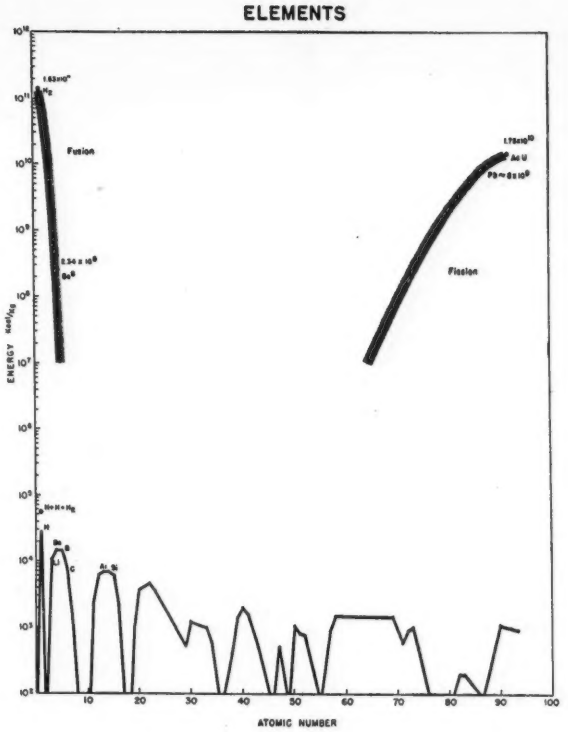


Figure 4. Gravimetric energy concentration of the elements.

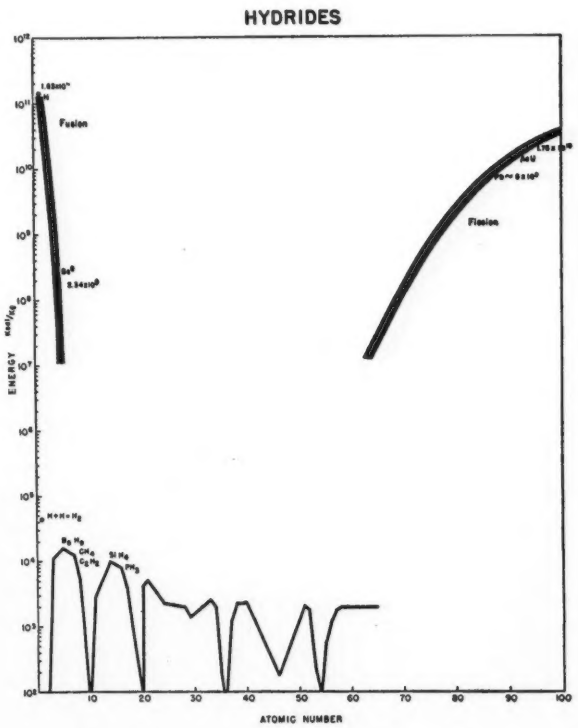


Figure 5. Gravimetric energy concentration of the hydrides.

boiler-reciprocating engine configuration, never reached the performance, both weightwise and economywise, obtained from a gasoline or diesel reciprocating engine.

Under these circumstances, the replacement of a combustor by a nuclear reactor in a gas-turbine propulsion system may hardly be expected to be the optimum application of nuclear energy. Consequently, it is felt that new vistas and methods of exploitation of the new energy source should be sought.

Solar Aviation

The next milepost in transportation will be set by the establishment of solar or interplanetary aviation.

In the case of terrestrial aviation, the Wright brothers' contemporaries were convinced that it was imperative to use the best developed engine of their time, namely, the reciprocating steam engine; Wilbur and Orville however, being accidentally unorthodox, were successful

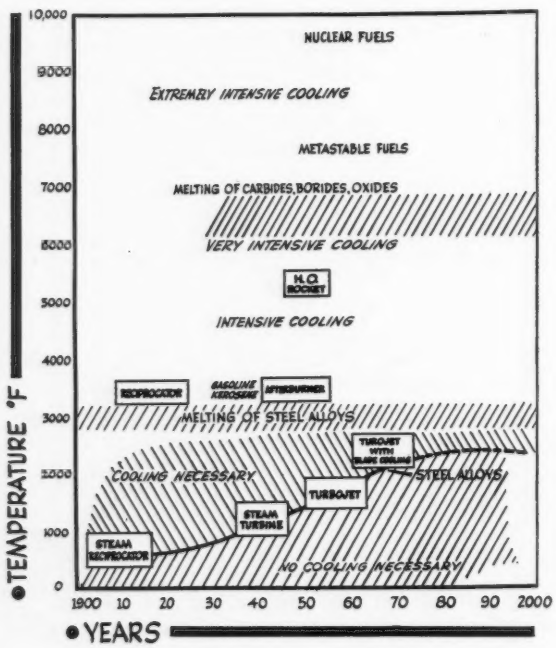


Figure 6. Trend in high temperature materials.

only by adopting the little developed, but far more promising, gasoline engine.

If history is to repeat itself in the next step of great aviation progress, it seems rather improbable that the chemical-fuel rocket will succeed; nevertheless, a more advanced and promising nuclear propulsion system may prove to be the winner in this contest.

Intragalactic Aviation

The second next milepost in transportation will be set by the establishment of intragalactic aviation. In the terrestrial and, up to a certain degree, interplanetary aviation, man is trying to conquer space; according to the theory of relativity, time and space cannot very well be separated as independent concepts as they are closely related by a universal constant, the speed of light. It is felt that man's objective in intragalactic aviation will be the conquest of both time and space. Such an objective may arouse a great storm of philosophical discussions and it is hardly advisable to speculate the consequences when the relativistic aspects of space and time will be the subject of everyday discussion.

TYPES OF PROPULSION SYSTEMS

Up to now no general configuration of the propulsion system suitable for the above three regions of aviation has been discussed.

The most general subdivision of future propulsion systems, that can be visualized today, for the above three regions of aviation are the following:

a) Mass ejection-reaction propulsion;

b) Field interaction propulsion.

Mass Ejection-Reaction Propulsion

In this mode of propulsion, energy is used to accelerate a given amount of more or less inert mass, which is ejected backwards; according to the action-reaction principle, a propulsive force equal to the change in momentum results. The energy that is spent to accelerate the ejected mass may be:

a) Thermal energy;

b) Non-thermal energy such as electric energy.

Some examples of the above were discussed in detail before[1]. Thermal energy propulsion systems are extremely limited in performance because of the present day lack of high temperature materials able to withstand temperatures of the order of 10,000° K.

Figure 6 shows the trend in high temperature materials. The conclusions from this picture are not very encouraging; however, these are only results from natural terrestrial materials. It has been hardly a decade since modern nuclear transmutations first produced artificial materials, particularly in the transuranic region. These new materials are not very different from normal terrestrial matter; however, the future may have reserved for us some very pleasant surprises. At present we do not understand the large variations of mass densities in the universe and we have hardly obtained a faint idea of the structure of matter. Table 2 gives a few examples of matter densities known in nature.

TABLE 2
MATTER DENSITIES

Species	Density (g/cm³)
Terra Firma	2 to 20
Sirius B	8×10^4
Van Maanen	3×10^5
Atomic Nucleus	2.2×10^{14}

Properties of matter at other than terrestrial conditions are only a speculation and, furthermore, nothing could be said about their artificial production.

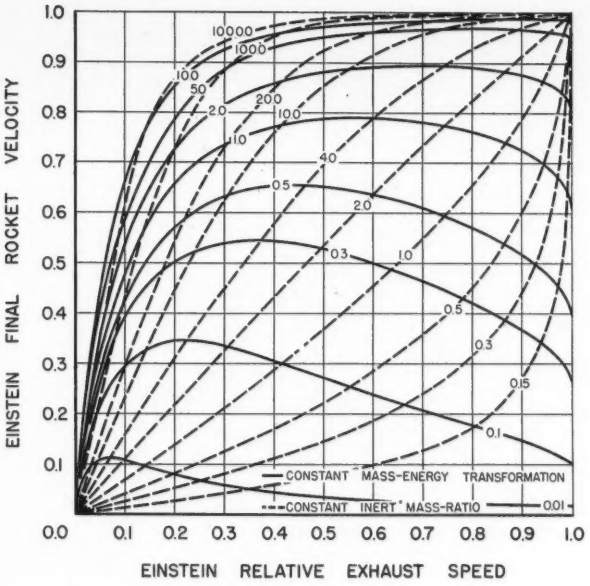


Figure 7. Generalized nuclear rocket performance.

Production of charged particles and acceleration through strong electromagnetic fields may provide a solution for obtaining higher performance than that obtained from thermal propulsion systems. The best solution seems to rest, however, in a direct transformation of nuclear into electromagnetic energy. Direct transformation of nuclear energy into propulsion seems to be rather remote, although not impossible.

Figure 7 shows the maximum attainable Einstein speed[a] of a vehicle as a function of the Einstein velocity of the ejected mass relative to the vehicle, at constant values of mass-energy transformation and propellant to useful load mass ratio. For comparison, Table 3 shows the energy performance characteristics of a number of nuclear reactions[2].

TABLE 3
NUCLEAR ENERGY LIBERATION

Reaction	Mass Defect	Relat ve Mas Energy Transfor-mation	Total Energy Libera-tion In *MeV*	Specific Energy Libera-tion
$4_1H^1 \rightarrow {}_2He^4 + 2_+e$	0.02859	0.00715	26.63	6.66
${}_1H^2 + {}_1H^2 \rightarrow {}_2He^4$	0.02552	0.00638	23.76	5.94
${}_1H^3 + {}_1H^2 \rightarrow {}_2He^4 + {}_0n^1$	0.01890	0.00378	17.60	3.52
${}_1H^3 + {}_1H^3 \rightarrow {}_2He^4 + 2_0n^1$	0.01228	0.002048	11.44	1.906
${}_1H^2 + {}_1H^2 \rightarrow {}_1H^3 + {}_1H^1$	0.00427	0.001067	3.98	0.995
${}_1H^2 + {}_1H^2 \rightarrow {}_2He^3 + {}_0n^1$	0.00349	0.000873	3.25	0.812
Thermal Fission $U^{235} + {}_0n^1$	0.0497	0.000843	184	0.785

[a]Einstein speed is that reduced to the speed of light.

From the above, it is seen that the relative mass-energy transformation is of the order of $\delta = 10^{-3}$ to 10^{-2}.

Analysis of the weight in a nuclear vehicle[3, 4] is given by the following equation:

$$M_i = (1 + p + \delta\alpha)\, M_f \qquad (1)$$

Where

M_i, M_f = the initial and final masses, respectively
pM_f = total ejected mass
αM_f = total active mass
$\delta\alpha M_f$ = mass transformed into energy
$(1-\delta\alpha)M_f$ = mass of nuclear by-products

The maximum performance is obtained when the nuclear by-products are used as part of the ejected (propelling) mass; under these circumstances $1 - \delta \leq p$; consequently, $(\delta\alpha)_{max} \cong \delta p$.

Table 4 gives the order of magnitudes of the maximum attainable Einstein speeds of the vehicle and the exhaust gases.

TABLE 4
NUCLEAR JET PROPULSION SYSTEMS PERFORMANCE PARAMETERS

	Symbol	Relative Mass-Energy Transformation					
		$\delta = 0.001$			$\delta = 0.01$		
Ratio of Ejected to Final Mass	p	4	10	100	4	10	100
Mass Transformation Into Energy	$\delta\alpha$	0.004	0.010	0.1000	0.040	0.100	1.0000
Einstein Maximum Vehicle Speed	$\frac{V}{C}$	0.076	0.108	.2034	0.220	0.324	0.5750
Einstein Exhaust Velocity	$\frac{W}{C}$	0.048	0.044	.0447	0.140	0.140	0.1404

From the above, the following conclusions may be drawn: Nuclear rocket propulsion systems seem quite adequate for terrestrial and solar aviation; however, for intragalactic aviation, fissionable and fusionable fuels do not appear to give the required Einstein vehicle speeds (of the order of 0.95) for reasonable propulsion system-vehicle configurations.

For given mass transformation into energy ($\delta\alpha$), the Einstein vehicle speed (V/C) around the maximum varies little with the Einstein exhaust-velocity (W/C) and the ejected to final mass ratio (p).

Again, for given ejected to final mass ratio ($p = 0.8$ to 10.0), the Einstein vehicle speed ($V/C = 0$ to 0.8) varies almost linearly with the Einstein exhaust velocity.

Field Interaction Propulsion

Propulsion systems of the mass ejection-reaction type seem to make rather extravagant use of their mass[4] consequently, other types, based on field interaction, should be considered. Unfortunately, it is premature to give engineering details of such propulsion systems.

CONCLUSIONS

Recognition of the new science of propulsion as an independent one will result in substantial progress in aviation.

Optimum application of nuclear energy can be realized only through the employment of new, radically different propulsion systems.

Jet Propulsion systems utilizing nuclear fuels seem adequate both for terrestrial and solar (interplanetary) aviation; however, existing information indicates that they seem to be inadequate for intragalactic aviation. This may be attributed to the extravagant use of their mass. It is concluded that other, more advanced propulsion methods, such as field interaction, should be employed in intragalactic propulsion systems.

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(We will announce the publication of Dr. Samaras' new book "Nuclear Propulsion and Engineering" as soon as it becomes available.)

The Calculation of the Wave Drag of an Arbitrary Slender Body by means of an Electrical Analogy Tank

(See Pages 169 to 177)

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$$I = -\int_0^1 \int_0^1 S''(x)\, S''(\xi)\, \log \left| x - \xi \right| dx\, d\xi$$

for $S'(o) = 0 = S'(1)$"

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THE CALCULATION OF THE WAVE DRAG OF AN ARBITRARY SLENDER BODY BY MEANS OF AN ELECTRICAL ANALOGY TANK†

by P. J. Pocock*

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SUMMARY

In view of the analogy between the supersonic wave drag of a slender body and the subsonic induced drag of an "equivalent" lifting line (first drawn to attention by von Kármán) the electric analogy tank developed by Malavard for solving the Prandtl lifting line equations can be used to calculate the wave drag of arbitrary slender bodies.

A Malavard type electric analogy tank at the National Aeronautical Establishment is described and its use illustrated by some example problems.

LIST OF SYMBOLS

a_n	Fourier coefficient
B	Decade box reading when setting electrode potentials
c	Wing chord
C	Decade box reading when measuring electrode circuit current
D	Wave drag
D_i	Induced drag
h	Electrode height
i	Electrode current
j	Electrode current density
l	Length of slender body or wing span
n	Number of electrodes or stations
q	Dynamic pressure
r	Body radius
r_o	Maximum body radius
S	Body cross-sectional area
t	Maximum thickness of body ($t = 2r_o$)
V	Voltage
w	Downwash velocity
x	Lengthwise co-ordinate of body or spanwise ordinate of wing
Δx	Effective electrode width
z	Vertical co-ordinate
C_D	Drag coefficient
C_L	Lift coefficient
C_p	Pressure coefficient
ξ	Auxiliary co-ordinate along x-axis
Γ	Circulation
ρ	Air density
η	$= x/l$
ϕ	Velocity potential
τ	$= t/l$
σ	Conductivity
μ	Constant scale factor (equation 16)

Subscripts

U	Signifying wing upper surface
L	Signifying wing lower surface
c	Values involved in calibration test to determine conductivity
$M, max.$	Signifying maximum value

1.0 INTRODUCTION

NUMERICAL methods[7,9] exist for calculating the supersonic wave drag of arbitrary slender bodies on the basis of linearized theory. In many instances these methods would necessitate the use of electronic calculating machines to obtain an answer in a reasonable time and to avoid the use of an excessive number of computer man-hours. The present paper describes an analogue method of solution involving the use of simple equipment; this method could be used where electronic calculating equipment is unavailable or when it is thought that the limitations imposed on the answer by the use of linearized theory does not justify the use of such equipment.

The analogue method involves the use of an electric analogy tank of the type developed by Malavard for the solution of lifting line equations and termed by Malavard a "wing calculator". That this tank can be used to calculate the wave drag of slender bodies is due to an analogy, pointed out by von Kármán at the Volta Congress, between the wave drag of a slender body and the induced drag of an "equivalent" lifting line (if $S(x)$ is the cross-sectional area distribution of a pointed slender body the wave drag is equal to the induced drag of a lifting line having a circulation distribution $US'(x)$ where U is the forward speed of the body).

†Paper read at the C.A.I. Annual General Meeting, in Toronto, on the 20th May, 1955.

*Head, Low Speed Aerodynamics Laboratory.

The present report describes a Malavard type analogy tank constructed at the National Aeronautical Establishment (much of it out of existing equipment), which satisfies the boundary conditions at 50 equi-spaced points along the body axis (or wing span). Fifty points were considered sufficient for most cases involving arbitrary slender bodies. Some example problems carried out with this tank are presented in Section 6.2; in the presentation enough detail is given to illustrate the methods of operating such an analogy tank.

2.0 WAVE DRAG OF A SLENDER BODY

One of the results of linearized theory that has been widely used is the equation for the zero-lift wave drag of a slender body, i.e.,

$$\frac{D}{q} = \frac{1}{2\pi} \int_o^l \int_o^l S''(x)\ S''(\xi)\ ln \left| \frac{l}{x-\xi} \right| dx\ d\xi \qquad (1)$$

where $S(x)$ is the cross-sectional area distribution of a body of length l for $o \leq x \leq l$. Also $S'(x)$ must be continuous for $o \leq x \leq l$ and $S'(o) = S'(l) = O$.

This expression can also be written as

$$\frac{D}{q} = -\frac{1}{2\pi} \int_o^l \int_o^l S''(x)\ S''(\xi)\ ln \left| x-\xi \right| dx\ d\xi \qquad (2)$$

In a paper presented at the Volta Congress in 1935 von Kármán[1] derived Eq. (2) for the wave drag of a slender ogive. Since that time the above equation has been utilized by Lighthill[2] and others[3]. Details regarding the derivation of the above equation are given in References 4 and 5.

The present report is not concerned with the range of useful application of the above equation, for example consideration of the limitations imposed by linearized theory, but rather with describing a means of evaluating the integral expression for an arbitrary $S(x)$ distribution if such is required.

3.0 ANALOGY BETWEEN WAVE DRAG OF SLENDER BODY AND INDUCED DRAG OF LIFTING LINE

In Reference 1 (and also Reference 6) von Kármán drew attention to an analogy that exists between the wave drag of slender bodies (as given by Eq. (1) or (2)) and the induced drag of a Prandtl lifting line. This analogy will be illustrated in what follows.

Prandtl's lifting line theory gives the following expression for the induced drag of a wing having a span l and a circulation distribution $\Gamma(x)$ (x and ξ are the spanwise co-ordinates).

$$D_i = \rho \int_o^l w(x)\ \Gamma(x)\ dx \qquad (3)$$

The downwash distribution, $w(x)$, is given by

$$w(x) = \int_o^l \frac{\Gamma'(\xi)}{x-\xi}\ d\xi \qquad (4)$$

and therefore

$$D_i = \rho \int_o^l \Gamma(x) \left\{ \int_o^l \frac{\Gamma'(\xi)}{x-\xi}\ d\xi \right\} dx \qquad (5)$$

Integration of Eq. (5) by parts and letting $\Gamma(o) = \Gamma(l) = O$ results in the following expression

$$D_i = -\frac{\rho}{4\pi} \int_o^l \int_o^l \Gamma'(x)\ \Gamma'(\xi)\ ln \left| x-\xi \right| dx\ d\xi \qquad (6)$$

It is immediately seen that Eq. (6) is transformed into Eq. (2) for the wave drag of a slender body if we let

$$\text{or} \quad \begin{aligned} \Gamma'(x) &= US''(x) \\ \Gamma(x) &= US'(x) \end{aligned} \qquad (7)$$

The condition $\Gamma(o) = \Gamma(l) = O$ is therefore equivalent to the condition $S'(o) = S'(l) = O$ which is required for Eq. (1) or (2).

In summary therefore, the wave drag of a slender body with area distribution $S(x)$ and length l with $S'(o) = S'(l) = O$ is identical to the subsonic induced drag of a lifting line of span l and with a circulation distribution $\Gamma(x) = US'(x)$.

4.0 MEANS OF EVALUATING WAVE DRAG EXPRESSION

Noting the analogy between the wave drag of a slender body and the induced drag of a lifting line (Section 3.0) Sears, in Reference 7, applied the traditional Fourier series method for solving lifting line problems to that of evaluating Eq. (2). He expanded $S'(x)$ in terms of of Fourier series and found that the wave drag bore a simple relation to the coefficients of the series, a result which was known of course from lifting line theory. That is, if $S'(x)$ is represented by the series

$$S'(x) = \sum_{n=1}^{\infty} a_n\ sin\ n\theta \qquad (8)$$

the wave drag is then given by the simple expression

$$D = \frac{\pi}{4}\ q \sum_{n=1}^{\infty} n\ a_n^2 \qquad (9)$$

where $x/l = \frac{1}{2}\ (1 - \cos\theta)$.

The above method would appear to be satisfactory for the case of an arbitrary slender body (e.g., a body defined by a numerical table of $S(x)$ values rather than by an analytical expression); however, the calculation would become tedious and time-consuming if many terms of the Fourier series were required; the time required to calculate the wave drag by this means might very well be incommensurate with the limitations of the linearized approach. Furthermore, this method requires $S'(x)$ to be determined; this can be done by numerical methods such as that of Reference 8. In Reference 9 it is pointed out that the necessity of determining $S'(x)$ can introduce "intolerable errors" and a method is developed there for obtaining the values of a_n (Eq. (9)) directly from $S(x)$; the resulting method still involves the determination of the constants of a Fourier series and

hence electronic calculating machines would still be necessary if a large number of Fourier terms were necessary.

The next section will describe a means for evaluating the expression for wave drag by means of an electrical analogy tank.

5.0 DETERMINATION OF WAVE DRAG BY MEANS OF AN ELECTRICAL ANALOGY TANK

The analogy between the induced drag of a lifting line and the wave drag of a slender body (c.f. Section 3.0) allows one to draw upon the vast literature dealing with the solution of the lifting line in search of means for determining body wave drag. As has been shown (Section 4.0) the Fourier series method of dealing with the lifting line has already been put to use in regard to this problem. One method of solving the Prandtl lifting line equations is by means of an electrical analogy tank; such a tank is described by Malavard in Reference 10.

The remaining part of the present report will be devoted to a brief explanation of the principles of the analogy tank originated by Malavard as well as some results obtained at the National Aeronautical Establishment with a Malavard type tank.

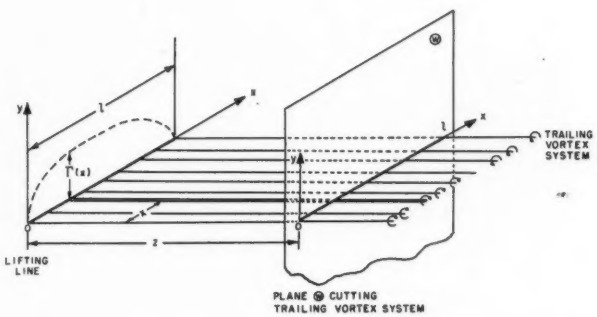


Figure 1. Schematic diagram of lifting line and associated trailing vortex system.

5.1 The Trefftz Plane

Figure 1 shows schematically a lifting line with its associated system of free trailing vortices; also indicated is the "trace" or "cut" made in a plane, W, perpendicular to the wake. When plane W cuts the vortex wake at an infinite distance ($z = \infty$) behind the lifting line it is called the Trefftz plane. The flow in the Trefftz plane can be treated as two-dimensional, and there exist simple relations between this two-dimensional flow and the circulation distribution over the lifting line; this relationship is illustrated in the following:

At any spanwise station of a wing the lift force can be expressed as

$$C_L(x)\, c(x) = \int_{-\infty}^{+\infty} (C_{p_U} - C_{p_L})\, dz \qquad (10)$$

where U and L represent upper surface and lower surface respectively.

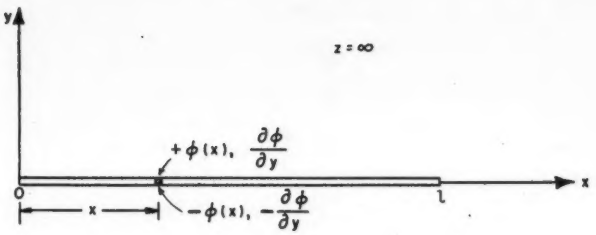


Figure 2a. Trace in Trefftz plane of trailing vortex sheet.

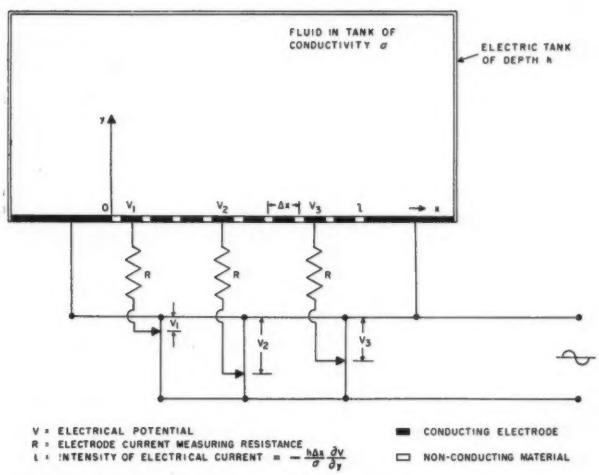


Figure 2b. Schematic diagram of Malavard's "wing calculator."

Now
$$C_p \approx 2\frac{U_z}{U} = \frac{2}{U}\frac{\partial \phi}{\partial z} \qquad (11)$$

and therefore
$$C_L(x)\, c(x) = \frac{2}{U}[\phi_U - \phi_L]_{z=\infty} \qquad (12)$$

the circulation being

$$\Gamma(x) = \frac{C_L(x)\, c(x)\, U}{2} = [\phi_U - \phi_L]_{z=\infty} \qquad (13)$$

The values of ϕ_U and ϕ_L are equal and opposite so that

$$\begin{aligned} \Gamma(x) &= 2\,\phi(x) \\ \phi(x) &= \tfrac{1}{2}\,\Gamma(x) \end{aligned} \qquad (14)$$

Also, the downwash at the Trefftz plans is twice that at the wing

$$w(x) = \frac{1}{2}\, w(x)_{z=\infty} = -\frac{1}{2}\left(\frac{\partial \phi}{\partial y}\right)_{z=\infty} \qquad (15)$$

Eqs. (14) and (15) show explicitly the desired relationship between the flow in the Trefftz plane and the circulation and downwash at the wing or lifting line. This relationship allows great simplification in many problems of applied wing theory inasmuch as a complex three-dimensional flow field is reduced to a two-dimensional potential problem.

5.2 Malavard's "Wing Calculator"

The trace of the trailing vortex sheet in the Trefftz plane is shown in Figure 2(a). The two-dimensional potential flow in the Trefftz plane is directly analogous to the "flow field" of a two-dimensional conducting sheet geometrically similar to the trace of the trailing vortices, which is surrounded by an unbounded fluid of conductivity dissimilar to the conducting sheet if the distribution of electrical potential is proportional to the distribution of velocity potential around the cut in the Trefftz plane; also, current density normal to the conducting sheet becomes analogous to the downwash in the hydrodynamic case.

The idealized electrical analogue mentioned above can be approached by means of a non-conducting plate in a conducting fluid, the surface of the plate being covered with a sufficient number of discrete electrodes to give a satisfactory representation of the desired potential distributions. Malavard constructed such an electrical analogue[10] and demonstrated its usefulness and accuracy for a variety of problems in applied wing theory.

Due to symmetry, the electrical analogy tank has to represent only the upper or lower half of the Trefftz plane; the electrodes extending from each end of the wake electrode system to the walls of the tank are grounded, thus ensuring that the electric analogue gives a true representation of the Trefftz half plane.

In operating the electric tank, either the electrode potentials are fixed (representing wing circulation distribution) and the resulting distribution of electrode currents measured (representing the downwash distribution), or the inverse operation can be carried out. The procedure for determining the span loading over a given wing having fixed chord and twist distributions, etc., is discussed by Malavard in Reference 10.

The use of a finite tank of conducting fluid introduces errors directly analogous to those caused by wind tunnel boundaries on model wings. The appropriate corrections can be found from existing literature concerned with wind tunnel boundary corrections. However, a suitable choice of size for the tank of conducting fluid can make the correction negligible. In Section 7.0 an interference free tank is described.

6.0 N.A.E. ELECTRICAL ANALOGY TANK

6.1 Description of Apparatus

The majority of the components needed for a Malavard type electrical analogy tank or "wing calculator" were already on hand in the laboratory and, therefore, it was possible to put together a "wing calculator" at very little cost. The main components are:

(*a*) *Electrode potential control panel.* This consists, essentially, of an array of potentiometers connected in series with the individual electrodes representing the cut in the Trefftz plane. Such a panel was already on hand for a three-diminesional lifting surface analogy tank developed by W. F. Campbell[11].

(*b*) *Large shallow water basin or "electric tank".* A large two-dimensional electric tank for plotting streamlines about aerofoils, etc., was on hand. Tap water was used as the conducting fluid.

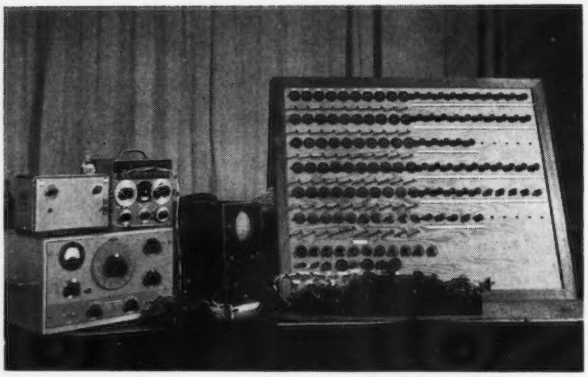


Figure 3a. N.A.E. analogy tank: control panel and associated apparatus.

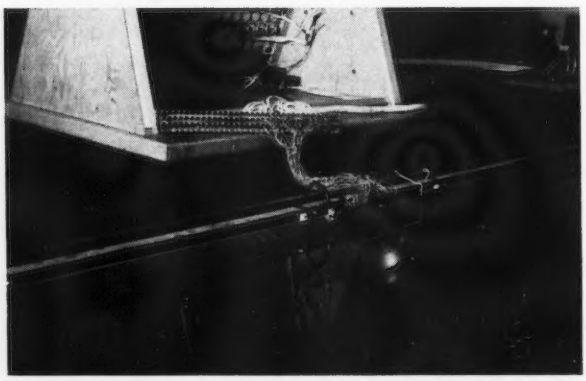


Figure 3b. N.A.E. analogy tank: analogy tank and electrode system.

(*c*) *Electrode plate.* An electrode plate representing the cut in the Trefftz plane had to be made. Figure 3 shows some general views of the equipment.

A signal generator is used to supply power to the system at 2,000 cps. A decade box across the input lines is used to establish a preassigned potential which is matched on the required electrode by adjusting the potentiometer in the electrode circuit and an oscilloscope is used to determine whether or not the two potentials are equal.

When all the electrodes have been set at the required potentials the currents in each electrode circuit are measured.

An electrode plate with 50 electrodes was chosen. Initially, the electrodes were formed by means of silver paint applied to a non-conducting plastic sheet. However, the dimensional accuracy was not sufficient and another method had to be found. Figure 4 shows the electrode plate now in use and shows schematically how it was fabricated. The ratio of electrode width to inter-electrode insulating space is 3:1.

6.2 Some Example Problems

6.2.1 *Non-dimensional Representation*

In relating quantities in the Trefftz plane to their analogous quantity in the electric tank, non-dimensional notation is very useful. The relation between analogous quantities is given below.

$$\frac{d(S/l^2)}{d\eta} = \frac{\Gamma(\eta)}{Ul} = \frac{2\,\phi(\eta)}{Ul} = \frac{2\mu\,V(\eta)}{V_{max}} \qquad (16)$$

slender body — wing — Trefftz plane — analogy tank

where

$$\eta = x/l \qquad (17)$$

and μ is a constant. The downwash equation for lifting line theory (Eq. (4)) may now be written in terms of the above non-dimensional parameters, for example

$$\frac{w}{U} = \frac{1}{4\pi}\int_0^1 \frac{d}{d\eta}\left(\frac{\Gamma}{Ul}\right)\frac{d\eta_1}{\eta-\eta_1} = \frac{1}{4\pi}\int_0^1 \frac{d^2(S/l^2)}{d\eta^2}\,\frac{d\eta_1}{\eta-\eta_1} \qquad (18)$$

6.2.2 *Parabolic Body of Revolution*

The equation for the radius of a parabolic body of revolution is

$$r(\eta) = 2t\,(\eta-\eta^2) = 2\tau l\,(\eta-\eta^2) \qquad (19)$$

where

$$\tau = (t/l) = \frac{2r_o}{l} \qquad (20)$$

r_o being the maximum radius of the body.

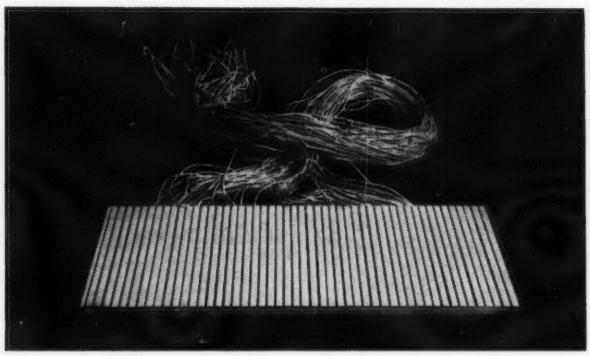


Figure 4a. Analogy tank electrode plate: 50-element electrode plate.

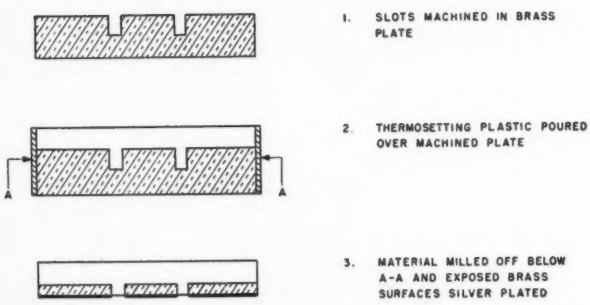


Figure 4b. Analogy tank electrode plate: Schematic diagram showing method of making electrode plate.

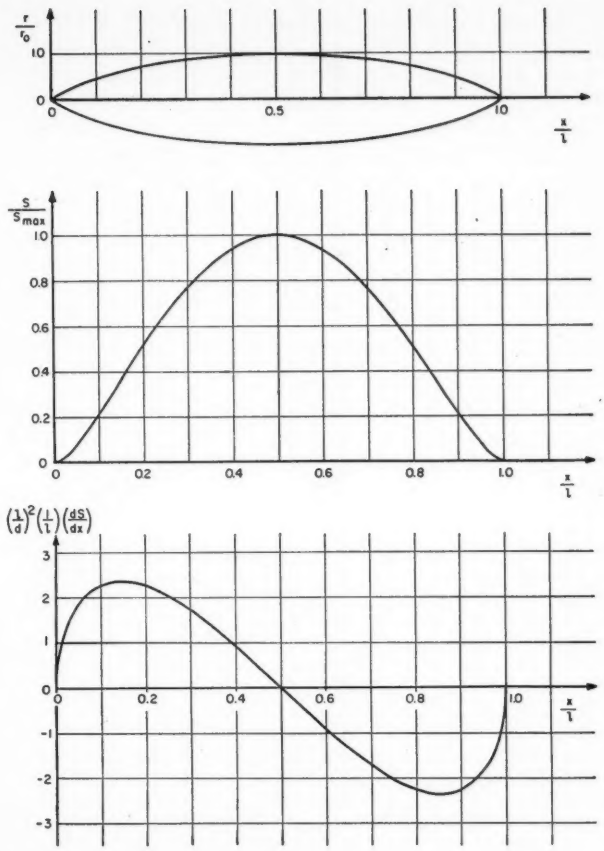


Figure 5. Geometrical details of parabolic body. $\frac{r}{r_0} = 4\left[\left(\frac{x}{l}\right) - \left(\frac{x}{l}\right)^2\right]$

The area distribution is

$$\frac{S}{S_{max.}} = 16\,(\eta-\eta^2)^2 \qquad (21)$$

The non-dimensional circulation for the equivalent lifting line can be found from the slope of the area distribution, viz:

$$\frac{1}{\tau^2}\left(\frac{\Gamma(\eta)}{Ul}\right) = \frac{d(S/l^2)}{\tau^2\,d\eta} = 8\pi\,(\eta-\eta^2)\,(1-2\eta) \qquad (22)$$

Figure 5 shows the radius and area distribution of a parabolic body as well as the slope of the area curve (or equivalent circulation distribution) given by Eq. (22).

The downwash distribution at the equivalent wing is found from Eqs. (22) and (18) to be

$$\frac{1}{\tau^2}\left(\frac{w}{U}\right) = 2\left[(1-6\eta+6\eta^2)\,ln\left|\frac{\eta}{\eta-1}\right| - 6\eta + 3\right] \qquad (23)$$

The supersonic wave drag as given by Eq. (1) can be calculated by using Eqs. (22) and (23) in combination with Eq. (3), the result being

$$\frac{C_D}{\tau^2} = \frac{1}{\tau^4}\,\frac{8}{\pi}\int_0^1 \left(\frac{w}{U}\right)\left(\frac{\Gamma}{Ul}\right)d\eta = 10.67 \qquad (24)$$

To determine an answer corresponding to the latter expression from the analogy tank the potential of the electrodes in the analogy tank must be set proportional to the slope of the area distribution curve of the body at equivalent stations, that is, Eq. (16) must be satisfied. As already mentioned, the electrode potentials are set at the required values by using an accurate decade resistance box and, therefore, Eq. (16) may be extended to include another term

$$\frac{d(S/l^2)}{d\eta} = 2\mu \frac{V(\eta)}{V_{max.}} = 2\mu \frac{B(\eta)}{B_{max.}} \tag{25}$$

where B is the setting of the decade box. The decade box setting is determined from the following expression

$$B = \frac{\left(\frac{S'(\eta)}{\tau^2}\right)}{\left(\frac{S'(\eta)}{\tau^2}\right)_{max.}} \times \bar{B} \tag{26}$$

by means of Eq. (22); $\bar{B}$ is the maximum value of decade box setting decided upon ($\bar{B} \leq B_{max}$). The value of μ is found from Eqs. (25) and (26) to be

$$\mu = \frac{\tau^2}{2} \frac{B_M}{\bar{B}} \left(\frac{S'(\eta)}{l^2}\right)_{max.} \tag{27}$$

The value of μ is needed to convert the currents measured in the electrode circuits to values of downwash as will be seen below.

From Eqs. (15) and (16) the downwash may be written as

$$\frac{w}{U} = -\frac{1}{2} \frac{\mu}{V_M} \frac{\partial V}{\partial \xi} \tag{28}$$

The current density over an electrode is

$$j = \frac{i}{h\Delta x} = \frac{1}{\sigma l} \frac{\partial V}{\partial \xi} \tag{29}$$

or

$$\frac{\partial V}{\partial \xi} = \frac{\sigma i}{h\Delta\eta} \tag{30}$$

so that

$$\frac{w}{U} = -\frac{1}{2} \left(\frac{\sigma\mu}{h\Delta\eta}\right) \frac{i}{V_M} \tag{31}$$

The conductivity, σ, of the water in the analogy tank must be determined before the current readings can be converted to downwash values. Although the conductivity can be measured in a conductivity cell it has been found more satisfactory to obtain it by setting a known problem in the tank. Standard practice with the N.A.E. tank is to represent a uniformly loaded line (horseshoe vortex) by connecting all the electrodes directly to the lines. The downwash at the mid-span of a horseshoe vortex is

$$\left(\frac{w}{U}\right)_c = -\frac{\Gamma c}{\pi l U} = -\frac{2\mu}{\pi} \frac{Vc}{V_{max}} = -\frac{1}{2} \left(\frac{\sigma\mu}{h\Delta\eta}\right) \frac{i_c}{V_M} \tag{32}$$

where the subscript c refers to quantities involved in the determination of conductivity; i_c is the current in the electrode circuit of the mid-span electrode when a constant voltage V_c is applied to all electrodes. The conductivity may now be written as

$$\left(\frac{\sigma\mu}{h\Delta\eta}\right) = \frac{4\mu}{\pi} \frac{V_c}{i_c} \tag{33}$$

and the downwash (Eq. (31)) becomes

$$\frac{w}{U} = -\frac{2\mu}{\mu} \left(\frac{V_c}{V_M}\right) \frac{i}{i_c} \tag{34}$$

The currents are determined by measuring the voltage drop across a known resistance; this voltage drop is balanced with the decade resistance box and this decade box reading, C say, is proportional to the electrode circuit current. In terms of decade box readings the downwash is

$$\frac{w}{U} = -\frac{2\mu}{\pi} \left(\frac{B_c}{B_M}\right) \frac{C}{C_c} \tag{35}$$

and the wave drag is

$$\frac{C_D}{\tau^2} = -\frac{8 B_c \left(\frac{S'(\eta)}{l^2}\right)_M^2}{\pi \bar{B}^2 C_c} \int_0^1 C(\eta)\, B(\eta)\, d\eta$$

$$\simeq \left(\frac{8}{\pi}\right) \left(\frac{B_c}{\bar{B}^2}\right) \frac{\left(\frac{S'(\eta)}{l^2}\right)_M^2}{C_c} \sum_{i=1}^{50} C_i\, B_i\, \Delta\eta \tag{36}$$

In cases where the summation indicated in Eq. (36) is sufficiently accurate, the wave drag can very quickly be determined from the decade box settings for electrode potential, B, and the decade box readings determined when measuring electrode circuit current, C.

The analogy tank results for the downwash distribution of the lifting line analogous to the parabolic body are compared in Figure 6 with the calculated distribution, and it can be seen that the agreement is good.

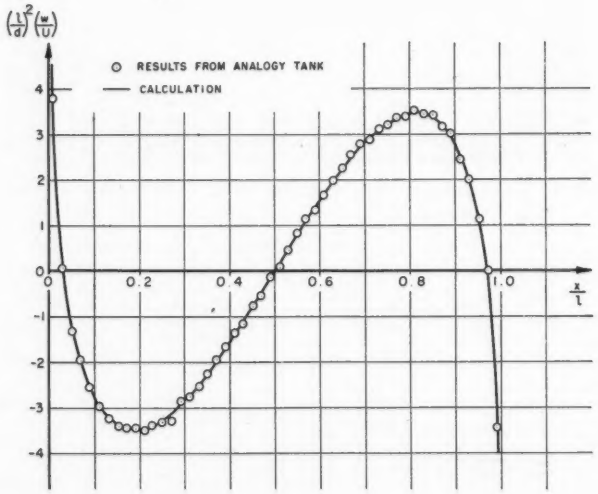
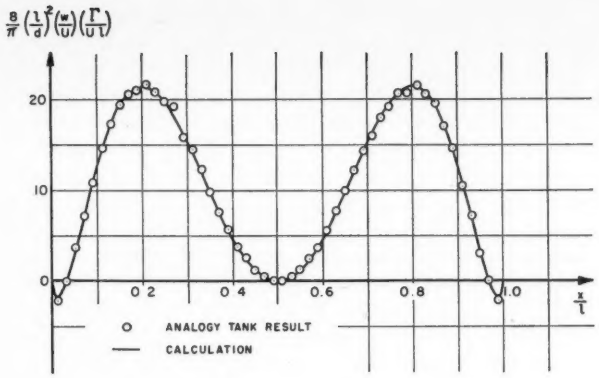


Figure 6. Downwash distribution corresponding to parabolic body.

$\Gamma(x) \equiv U\left(\frac{dS(x)}{dx}\right)$

$\frac{w}{U} \equiv \frac{1}{4\pi}\int_0^1 \frac{d}{d\eta}\left(\frac{\Gamma}{Ul}\right)\frac{d\eta}{\eta-\eta_1}$; $\eta = \frac{x}{l}$



WAVE DRAG COEFFICIENT (AREA UNDER ABOVE CURVE)

1. CALCULATED

$$C_D\left(\frac{1}{d}\right)^2 = \frac{8}{\pi}\left(\frac{1}{d}\right)^4 \int_0^1 \left(\frac{w}{U}\right)\left(\frac{\Gamma}{Ul}\right) d\eta = 10.67$$

2. APPROXIMATE INTEGRATION USING ANALOGY TANK RESULTS

$$C_D\left(\frac{1}{d}\right)^2 = \frac{8}{\pi}\left(\frac{1}{d}\right)^4 \sum_{i=1}^{50} \left(\frac{w}{U}\right)_i \left(\frac{\Gamma}{Ul}\right)_i \Delta\eta = 10.65$$

Figure 7. Parabolic body—calculations of wave drag.

Figure 7 contains a plot of the integrand of Eq. (24) against η; the wave drag of a parabolic body can be obtained by graphical integration of this curve; however, as indicated in Figure 7 this is not necessary as the value found by the summation indicated in Eq. (36) is $C_D/\tau^2 = 10.65$ which agrees well with the calculated value of 10.67.

6.2.3 *Sears-Haack Body*

The body of given length and volume, having the minimum supersonic wave drag according to linearized slender body theory, has been determined by Sears and Haack. The resulting body is often referred to as a Sears-Haack body; the body, shown in Figure 8, has a radius distribution

$$\frac{r}{r_o} = \sqrt{8}\,[\eta - \eta^2]^{3/4} \tag{37}$$

an area distribution

$$\frac{S}{S_{max.}} = 8\,[\eta - \eta^2]^{3/2} \tag{38}$$

The slope of the area distribution curve is

$$\frac{1}{\tau^2}\left(\frac{1}{l^2}\frac{dS}{d\eta}\right) = 3\pi\,(1-2\eta)\,(\eta-\eta^2)^{1/2} \tag{39}$$

Eqs. (38) and (39) are plotted in Figure 8.

The downwash at the analogous lifting line is

$$\frac{1}{\tau^2}\left(\frac{w}{U}\right) = \frac{3\pi}{2}\,(2\eta - 1) \tag{40}$$

Values found from Eq. (40) are compared with analogy tank results in Figure 9; the agreement is good except for the values obtained from the end electrodes.

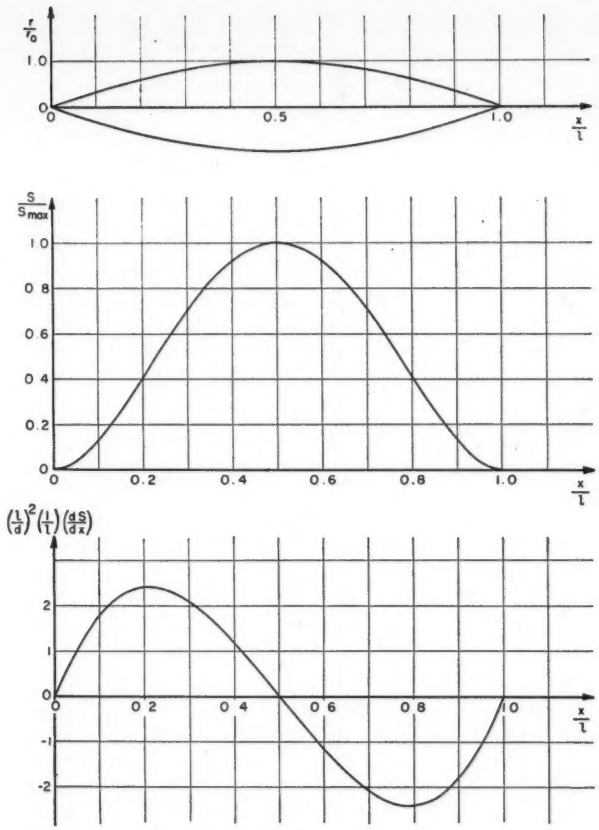


Figure 8. Geometrical details of Sears-Haack body.

$$\frac{r}{r_0} = \sqrt{8}\left[\left(\frac{x}{l}\right) - \left(\frac{x}{l}\right)^2\right]^{\frac{3}{4}}$$

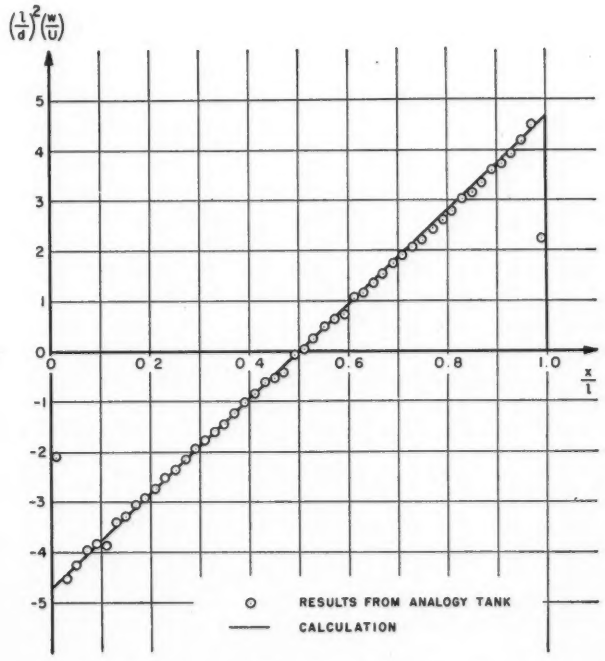
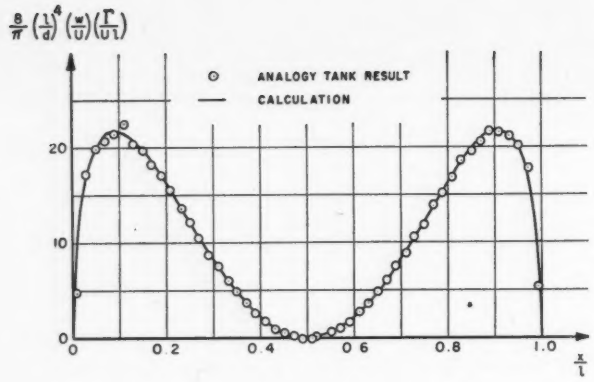


Figure 9. Downwash distribution corresponding to Sears-Haack body.



WAVE DRAG COEFFICIENT (AREA UNDER ABOVE CURVE)

1. CALCULATED

$$C_D\left(\frac{1}{d}\right)^2 = \frac{8}{\pi}\left(\frac{1}{d}\right)^4 \int_0^1 \left(\frac{w}{U}\right)\left(\frac{\Gamma}{U1}\right) d\eta = 11.10$$

2. APPROXIMATE INTEGRATION USING ANALOGY TANK RESULTS

$$C_D\left(\frac{1}{d}\right)^2 = \frac{8}{\pi}\left(\frac{1}{d}\right)^4 \sum_{i=1}^{50} \left(\frac{w}{U}\right)_i \left(\frac{\Gamma}{U1}\right)_i \Delta\eta = 10.90$$

Figure 10. Sears-Haack body—calculation of wave drag.

The argument of Eq. (24) is plotted in Figure 10. As indicated in this figure, carrying out the integration for wave drag by use of the summation in Eq. (36) results in a value of $C_D/\tau^2 = 10.90$ compared to the calculated theoretical value of 11.10. From a study of Figure 10 it is obvious that a graphical integration of the analogy tank results would give closer agreement with the theoretical value than the value found by the summation.

7.0 EXTENSIONS AND OTHER USES OF ANALOGY TANK

Essentially, the Malavard "wing calculator" solves an integral equation of the form found in the equation for the downwash due to a lifting line (Eq. (4)). This form of equation is quite common in aerodynamics, and therefore, the analogy tank described herein can be used for problems other than calculating the wave drag of slender bodies or for purely lifting line calculations; a few such uses are outlined below.

The velocity distribution in incompressible flow of a thin symmetrical aerofoil such as that shown in Figure 11 is given by the following equation[12]

$$V(x) \simeq U\left[1 + \frac{1}{\pi}\int_0^c \left(\frac{dy}{dx_1}\right)\frac{dx_1}{x-x_1}\right] \qquad (41)$$

where the notation is explained in the above figure.

The pressure coefficient is

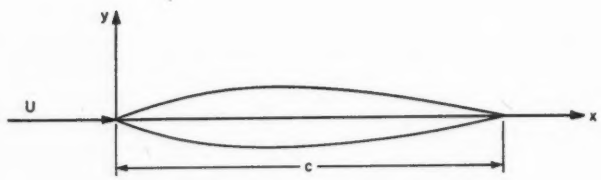
$$C_p = -\frac{2}{\pi}\int_0^c \left(\frac{dy}{dx_1}\right)\frac{dx_1}{x-x_1} \qquad (42)$$

Therefore, if the electrode potentials are made proportional to the aerofoil ordinates at corresponding stations, the measured electrode circuit currents are proportional to the local pressure coefficient; the inverse problem of finding the aerofoil shape, having a prescribed pressure distribution, can also be done.

With conventional round nose aerofoils there is the embarrassment of an infinite value of (dy/dx) to contend with at the leading edge; it is thought that this problem can be overcome when some two-dimensional problems are carried out in the analogy tank in the near future.

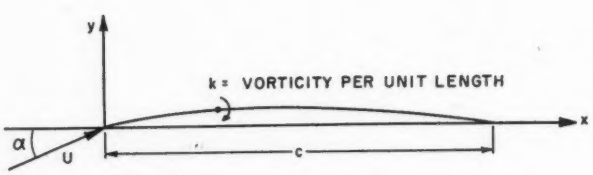
From Figure 12 it is seen that the analogy tank can be used for calculations concerned with aerofoil camber lines (notation in this figure from Reference 13).

During the last few years, due to geometrical change in wing platforms, wing lift distribution calculation has changed from the solution of the Prandtl lifting line equations (by Multhopp's method for example) to carrying out lengthy calculations required by various lifting surface theories. However, the latter trend was successfully avoided by Kuchemann in Reference 14,



$$V(x) \simeq U\left[1 + \frac{1}{\pi}\int_0^c \left(\frac{dy}{dx_1}\right)\frac{dx_1}{x-x_1}\right]$$

Figure 11. Velocity distribution over thin symmetrical aerofoil in incompressible flow.



u = PERTURBATION VELOCITY ON CAMBER LINE

$$k = 2u; \quad C_p = -\frac{2u}{U}$$

$$\frac{dy}{dx} = \alpha + \frac{1}{2\pi U}\int_0^c \frac{k\,dx_1}{x-x_1} = \alpha + \frac{1}{\pi U}\int_0^c \frac{u\,dx_1}{x-x_1}$$

Figure 12. Relation between shape and velocity distribution of "thin" camber lines in incompressible flow.

where he developed a method for calculating the surface loading on swept wings that once again involves the solution of the standard Prandtl lifting line equation. In view of the latter it may be that "lifting surface" calculations for a wide class of wings can be carried out by the use of the Malavard "wing calculator".

With regard to the equipment there are two developments that could be made:

(1) automatic voltage regulators installed in electrode circuits thus avoiding the iteration process in setting electrode potentials.

(2) use of a semi-circular tank which has no boundary interference and therefore would lead to a more compact apparatus.

The first modification mentioned above would reduce the time required to obtain an answer by a large factor and would enable the number of electrodes to be increased without the calculation time becoming unmanageable.

The trace of the wing in the Trefftz plane can be transformed into a circle by a Joukowski transformation. A circular (or semi-circular) analogy tank could be built to simulate the interior of the transformed slit in the Trefftz plane; this arrangement would have no boundary interference thus allowing a compact apparatus to be built. The latter type of tank would be particularly suited to the two-dimensional aerofoil problem as there would be a greater effective density of electrode over the nose section (i.e., equal increments in θ leads to a "crowding" at $x = o$ and $x = l$ where $x/l = \frac{1}{2}$ $(1 - \cos\theta)$).

8.0 DISCUSSION AND CONCLUSION

In summary, the means for solving the integral expression for the supersonic wave drag of an arbitrary slender body, Eqs. (1), (2) are:

(*a*) *Direct integration.* If the area distribution, $S(x)$, can be explicitly expressed in an analytical form.

(*b*) *Sears method.* $S'(x)$ of body expanded in terms of a Fourier series; if many terms are required electronic calculating machines are necessary to reduce calculation time.

(*c*) *Routledge-Lord-Eminton method.* To overcome inaccuracies in $S'(x)$ determination this method begins with Fourier expansion of area distribution $S(x)$. As in (*b*) above, electronic computing equipment required if many Fourier terms are found necessary.

(*d*) *Electrical analogy tank method.* If $S'(x)$ is available the wave drag can be found by means of an electrical analogy tank (Malavard's "wing calculator") as described herein.

Methods (*b*) and (*d*) are directly comparable; the 50-electrode analogy equipment described in the present report can be used to obtain a final answer in 2 to 3 hours, whereas a similar number of terms in a Fourier series would require electronic calculating machines if the answer were to be obtained in a reasonable time and number of computer man-hours.

Whether or not the inaccuracies involved in determining $S'(x)$ from a table of $S(x)$ values, say, are serious, would of course depend on the individual case; however, it is thought that method (*c*) above[9], would not have to be resorted to, a combined graphical and numerical determination of $S'(x)$ being satisfactory for most cases.

Cases could occur where analytical expressions for $S(x)$ (and $S(x)$) are available, but where the direct integration of Eq. (1) or (2) is not possible. Here, $S'(x)$ could be calculated and the results used to obtain a solution with the analogy tank. Nonweiler[15] gives an indication of where such a case might occur; he finds that the drag of a fully-tapered swept wing calculated by linear theory in the limiting condition

$$\sqrt{M^2 - 1}\,\cot\Lambda_o \to 0$$

is identical with the result obtained from slender body theory (i.e. Eqs. (1) and (2)) for such a wing. In view of the above the supersonic wave drag of a certain class of wings can be found from the slender body wave drag equation. However, if the aerofoil shape were any but the most simple (e.g. biconvex), it is doubtful if a direct integration of Eq. (1) could be carried out; but $S'(x)$ could be obtained to any degree of accuracy and the wave drag obtained from an analogy tank.

9.0 ACKNOWLEDGMENT

The author wishes to thank Mr. W. F. Campbell for putting at his disposal much of the equipment used in the present tests as well as for useful advice concerning all phases of the work described herein.

For References See Page 168

THE HELICOPTER AND CANADIAN DEVELOPMENT†

presented by Okanagan Helicopters Ltd.

THE helicopter's facility for flying forward, backward, sideways, and to hover at zero ground speed, plus its ability to alight on clear level areas little longer than the machine itself, have made this aircraft invaluable in various types of exploratory and developmental work that are going on in the world today.

INITIAL OPERATIONS

Early operators of the helicopter had no difficulty flying at low altitudes, but little was understood about operating helicopters at altitudes of, say, 5000 feet. When operators first attempted to work in the higher altitudes, the machine did not have quite enough power or performance for useful operation there. However, with more experience, and the actual improvement made in the helicopter itself, the problems presented by varying air density, etc., gradually became solved, until today helicopter pilots may be as adept at landing on mountain peaks as on the floors of valleys.

The first commercially-licensed helicopter was the Bell 47B model, which was powered by a 178 hp Franklin engine. This machine could carry one passenger as well as the pilot and had a useful payload of 400 lb. It had an endurance of three hours and a maximum range of roughly 200 miles with a cruising speed of 75 mph.

Although the Bell was originally licensed with wheel-type landing gear, this was soon modified to a skid-type, which was found to be more suitable for landing on rough ground, as it enabled the machine to straddle pot-holes, rocks, etc., and prevented it sinking into bogs. With a view to obtaining increased performance, the fuselage and tail boom were stripped thus decreasing the weight of the helicopter and also improving the handling qualities in turbulent air or in nasty wind conditions. The controls also were gradually improved and finally, the Bell became powered with a 200 hp engine. Today it can carry a payload of between 500 and 600 lb into altitudes over a mile high, depending on such variables as temperature, turbulence, etc.

One of the first Bells on the commercial market was purchased by Carl Agar, now Vice-President of Operations of Okanagan Helicopters Ltd. of Vancouver, B.C. The first use he made of the novel aircraft was for spraying orchards. However, this type of work presented problems of a technical nature, the work was seasonal, and the volume insufficient to merit the high cost of helicopter operation. For these reasons, other types of work were sought. Mr. Agar envisioned the use of the helicopter for various types of aerial-survey work and pursuaded the government of British Columbia to try it. As a result, work was performed for the Provincial Topographic Division of the Department of Lands and Forests and proved to be so successful that this division has employed helicopters for its field operations ever since. It was found that the helicopter was able to transport men and their equipment into otherwise inaccessible areas, moving them quickly from mountain peak to mountain peak when desired. It is not difficult to understand the saving in time and energy that resulted. Work that had taken years to do by the old method of packhorse and foot travel was accomplished in a single season.

KITIMAT PROJECT

However, it was the use to which helicopters were put during the construction of the Aluminum Company's project in the Kemano-Kitimat area of British Columbia that really brought the helicopter into its own and provided an opportunity to prove its versatility. Throughout the entire project, helicopters were an essential part of the equipment. Their very first task was to search out the best route for the transmission line. In twenty flying hours this work was completed, whereas it would have taken years for a survey party on foot to obtain similar data. The route for a ten-mile road was also surveyed from a helicopter, and when the actual building of the road commenced, the helicopter went on ahead, bringing in equipment and supplies in order to set up camps, one of them being large enough to house 500 men. These camps were all serviced by helicopter throughout the project.

A very exacting triangulation survey was carried out by the Bell helicopter in determining the route of the ten-mile tunnel.

The preliminary survey work was performed by the Bell helicopter, but when the actual construction commenced, the Sikorsky S-55 was brought in to handle the heavier types of equipment that required transportation. The S-55 is capable of carrying between 1000 and 1500 lb as against the 500 to 600 lb carried by the Bell.

†Paper read by J. C. CHARLESON at the Annual General Meeting of the C.A.I. in Toronto on the 20th May, 1955.



Figure 1. Sikorsky S-55 with an aluminum cross member used in the construction of transmission towers of the Alcan project.

Seven passengers may be carried in addition to the pilot. Loads may be carried internally in the cabin, or externally, slung beneath the helicopter. (Figure 1) An ingenious method has been devised whereby loads can be picked up or dropped in a matter of seconds. The maximum range of this ship is 350 miles, the maximum endurance four and one-half hours, and the cruising speed 80 mph.

Prior to the actual building of the transmission line on the Kemano project, an experimental section of line was strung between two towers at 5200 feet, all material being brought in by helicopter. The materials to build a cabin, equipment, supplies and men were brought in to the 4500 ft. level for the purpose of constructing a weather station.

Little or no problem was presented with regard to mountain landing-spots for the helicopter. The Sikorsky could drop or pick up its loads without having to land, or by merely touching down momentarily. As for the Bells, where sections of the mountains were too steep for regular landings, materials and carpenters were dropped onto the locations where landing platforms as small as 10 ft. x 10 ft. were erected (Figure 2); sometimes poles from the vicinity were used, instead of carrying lumber in (Figure 3). During the course of the project, hundreds of landings and takeoffs were made to and from these sites.

The use of helicopters on this project is well-known and has been much publicized. Without their help, it is considered that the project would have been at least a year behind schedule. On this operation, helicopters were not the only method of transportation used, but were only used when other means of transportation were unavailable or impractical. The helicopters transported every conceivable type of equipment to and from camp sites, from nails to bundles of lumber 30 feet long, power plants, tools, drilling equipment, food supplies, and building materials. (Figure 4).

While the major part of the project is completed, the helicopters will remain for emergency and patrol purposes throughout the years. Foot travel over the route in the winter is most hazardous and nigh on impossible, because of the heavy snow fall and slide potential. Snow depth up to 30 feet is not uncommon at altitude, throughout the area. Helicopter patrol will continue to be used to determine the condition of insulators, etc., on the transmission line. Any movement of towers or slide indications are readily observed during the slow flight of which the helicopter is capable. Only recently the helicopters played an important part in restoring power, by locating the damage done by a snowslide and carrying in men and materials to effect repairs.



Figure 2. Bell 47 D1 on a typical landing platform used during the Alcan project.



Figure 3. Bell 47 D1 on a temporary landing platform at the 3,300 ft. level during the Alcan operations.



Figure 4. Sikorsky S-55 with a sling load of lumber approaching the dropping zone on the summit of the Alcan transmission line.



Figure 5. Drilling equipment being loaded into a net for sling loading to the Sikorsky S-55.

PIPELINE PATROL

Another type of patrol performed by the helicopter is the patrol of Trans Mountain's oil pipeline running from Vancouver to Edmonton, a distance of 712 miles. A complete patrol of the line is done every ten days. The flight of the helicopter permits close scrutiny of the line and it may land adjacent to the line for still closer observation if necessary.

MINING APPLICATIONS

The mining world was very quick to see the possibilities of the helicopter. Mineral exploration, to a large extent, had been carried out by the old-time prospector, either on foot or using packhorses. This method was slow and discouraging and some rugged spots were not accessible to these men. But the helicopter changed this picture. Experienced mountain helicopter-pilots are able to transport prospectors and their equipment into such regions in a very short space of time, and bring them out when their work there is finished. The ability of the helicopter to hover and move at a very slow speed permits aerial inspection of outcrops and talus slopes. Chosen areas may be covered systematically and usually the small landing area necessary permits landings near if not right at the points desired. Searching for uranium from a helicopter, using an airborne instrument, the scintillometer, has proven successful.

Diamond drills, etc., are commonly carried into mineral sites in the exploratory stage. The use of the helicopter thus dispenses with the building of roads until such time as the property is proven to warrant such an expenditure.

OIL EXPLORATIONS

The search for oil has been facilitated by the helicopter. It has enabled gravity-meter crews to get readings in terrain where it would have been impossible for them to operate without this particular type of transportation.



Figure 6. Sikorsky S-55 carrying a sling load.

Also in this field, a whole new vista has recently been opened up to the helicopter. As the result of a test operation conducted last year, it was proven that helicopters, the S-55 in conjunction with the Bell, could provide the necessary transportation for a complete seismic operation, from the movement of brush-cutting crews to the carrying and spotting of drilling rigs, as well as the delicate seismic instruments themselves. Where it was found to be most practical, the equipment was carried slung beneath the S-55 helicopter. (Figures 5 and 6).

The task of transporting this heavy, expensive equipment, suspended beneath the helicopter, results in considerable mental strain for the pilot. Very fine and exacting manipulation of the controls is required as he must hover the aircraft while loads are attached to and released from the hook, suspended outside his vision beneath the machine, and equipment must be set down in predetermined locations. As the distance between locations is one third to two thirds of a mile, many landings and

takeoffs are required in a very short space of time, resulting in a high fatigue level in the pilots. At one stage of this particular operation, the Bell pilot made a takeoff or landing every 2½ minutes over a period of five hours.

The helicopter was tested for seismic operation in the area chosen because there were no roads. A road of sorts could be bulldozed out for use in the winter months when the ground was firm, but it would be quite unfit for use in the period between break-up and freeze-up when the ground was very soft. As the need for a year-round operation was indicated, the helicopter was tried. It is in situations of this kind where the helicopter provides invaluable service, supplying transportation where no other form of it is available, and the importance of getting the job done merits the cost.

While the test operation proved that the S-55 could provide the necessary transportation for seismic equipment (components weighing in the vicinity of 960 lb), helicopter operators know that when the S-58 becomes available for commercial use, this particular type of operation may be handled with ease, as the S-58 is capable of carrying a payload of 5000 lb, as compared to that of the S-55 of between 1000 and 1500 lb, depending, of course, on variables such as temperature, turbulence, etc.

ICE BREAKER OPERATIONS

The great development programme going on in Canada's north country is taking the helicopter farther from civilization. Playing their part in this work are Canada's two icebreakers, the *C. D. Howe* and the *d'Iberville*, which ply across the Arctic from Labrador and among the islands to the north of the Canadian mainland. As the *C. D. Howe* found the helicopter to be of great assistance in its work, the *d'Iberville*, the largest ship of its kind in the world, had two Bells installed, with heated hangar and parts stores built right into the superstructure of the ship. A spot on the after deck is the landing place. One can imagine the skill required of the pilot who must land his ship on this postage-stamp landing spot, the ship often rolling the while. The Bells, of course, were slightly modified for this work. Floats were used instead of the usual landing gear. A specially designed transmitter, working on the ship's marine frequency, was installed, also defrosting fans to keep the bubble ice-free. Thin aluminum plates were fastened on the underside of the pontoons as protection against possible puncturing when landing on the frozen terrain, or from scuffing when landing or taking off from the steel deck. This equipment weighed less than 45 lb and did not noticeably affect the performance.

It was found that the helicopter proved to be of greatest value to the ship's company in assisting navigation into and out of ice-bound harbours, thus saving time and increasing the mileage covered in the short navigational season. At times, when the ship appeared to be completely ice-bound, the helicopter was able to search out a route that would enable the icebreaker to push through to clear water. Air photography of course could be carried on which supplied information re harbour facilities, etc., and assisted in the revision of maps and charts. Some mercy missions were performed, the ship's doctor being ferried out to locations requiring aid otherwise unobtainable. Advance information regarding approaching ice floes was radioed back to the ship by the helicopter. In one year the *C. D. Howe* travelled some 12,000 miles accomplishing a great deal more with the use of helicopters than could have been done otherwise.

GEOLOGICAL SURVEYS

This year, helicopters are taking part in what is perhaps the most important phase of northern development, that is, the geological surveys that are being conducted there. In order to obtain greater results from the geological survey of the fifteen islands lying in the Arctic north of the Canadian mainland, the Canadian government decided to employ helicopters. Past surveys indicated that mineral and oil possibilities are such as to merit additional surveys.

The Franklin operation, as this year's expedition is called, will commence out of Resolute Bay on Cornwallis Island, the most southerly of five such bases, and situated 300 miles north of the magnetic pole. It will extend over the period from June to September and, as the work progresses the geologists will work still northward. Some 7,500 miles of air survey is within reach of the base at Resolute Bay. Radiating out from the main bases, as far as 160 miles in all directions, aerial survey routes run out, ending in locations where temporary tent camps will be set up—all by helicopter. The geologists will be moved from one location to another as the work progresses. It is in this type of transportation from the main camp to the outer tent-camp locations, and the servicing of such that the helicopters will be used. All manner of supplies will be ferried out by them, including dog teams. During the actual ferry flights, the geologists will take the opportunity to survey the routes from the air. Navigation will be difficult at times during this operation when wide bodies of sea ice must be traversed and land marks will be difficult to distinguish. The gyrocompass and sun compass will be used in these instances.

It is possible that this year's operation will see the completion of the survey work out of the Resolute Bay base only, but even so, the amount of territory surveyed will be phenomenal as compared with the work accomplished without the use of the helicopter.

FUTURE POSSIBILITIES

Another use for the Bell helicopter has been found this year operating out from a heliport constructed on the deck of a sealing vessel. It enables the ship's captain to search out the sealing grounds and return to the ship with first-hand information.

A great potential for the use of the helicopter lies in the forest industry. So far, this field remains practically untouched. Some timber cruising has been done by helicopter and some spraying. However, an experiment was recently conducted in the laying of poison bait to eliminate rodents who eat the seeds as well as the seedlings intended to perpetuate our forests. The helicopter conducted what was considered a very successful operation in this regard. The actual baiting was done from approximately 100 feet at 45 mph, the bait, in the form of colored, poisoned wheat, being dropped from hoppers and sprayed very evenly over the chosen territory.

Forest reseeding has also been done via the helicopter. The seed was dropped from hoppers and reached the ground with approximately 1 seed to every four feet. With the use of ground markers, the desired area was evenly supplied with seed, 80 acres being applied in ten minutes. By hand time, 80 man days would have been required. As this experiment was judged highly successful it is considered that this type of work alone would provide much work for helicopters, especially if governmental departments availed themselves of the service.

Fighting fires is another branch of the forest industry where the helicopter could be utilized to great advantage. Conveying and landing men quickly in close proximity to small spot fires could well prevent them growing to larger proportions. Also, removing injured personnel could be accomplished quickly by this versatile little aircraft.

Helicopters, of course, are very valuable for use in rescue work. In fact, this was their main use during the Korean war and many rescues were effected that would not have been accomplished otherwise.

In the Province of Newfoundland, where rail and road transportation are practically non-existent, the helicopter has proven to be a great boon. The Fisheries Department there now uses a helicopter for transportation of key personnel throughout the island. This helicopter was also used on many occasions as an air ambulance with the result that the Provincial Department of Health chartered a Bell model 47G, equipped with covered litters, to provide air-ambulance service for the outposts, scattered over the 900-mile coastline.

Helicopter operators are, of course, looking forward to the licensing of the large passenger helicopter in a few years' time, but it is expected that this ship will be used on lines in the nature of feeder runs, such as between outlying airports and city centres and between cities in heavily-populated areas.

At the present time, practically nothing is known about what may be expected in the way of economics on this type of helicopter operation. It is the experience of operators of present-day helicopters that many hours of maintenance are required for one hour of helicopter flying, if the helicopter is to operate properly. Therefore, one of the determining factors regarding the use made of the passenger helicopter when it is commercially available, will be the economics of its operation.

New uses for helicopters are envisioned, such as by cattle ranches during round-up time; also in the searching for strays and for the inspection and repairing of ranch fences. The transporting of mail by helicopter between airports and post office heliports may become common practice. In the construction field, with the building of bigger helicopters, the size of the equipment handled will be limited only by the size of the helicopter itself, and it is not without the realm of possibility that prefabricated houses, already assembled, will be set down on their foundations by helicopter, in settled and unsettled areas alike. In fact, construction firms will order helicopters as they now order bull-dozers. However, as long as there are areas requiring exploration and development, there the helicopters will be, supplying transportation where no other form of it exists, carrying men and materials into otherwise inaccessible places; veritably, making mole-hills out of mountains.

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THE RΘ-DR COMPUTER SYSTEM†

by W. F. Haehnel* and J. L. McKelvie**

P.S.C. Applied Research Ltd.

SUMMARY

The RΘ-DR System is a ground position computer, which provides position data in polar co-ordinates with respect to a selected base or reference point. Any alternative base or reference point may be selected during flight. Precise adjustments may readily be made to the computed ground position whenever accurate fixes are obtained from other sources. The position data is presented in conjunction with track in such a form that homing information is available at all times. Homing can be carried out merely by changing heading to align the concentric track and bearing pointers.

INTRODUCTION

THIS paper discusses a new automatic navigation equipment, the RΘ-DR Computer System, invented by W/C J. G. Wright, R.C.A.F., and developed and produced by PSC Applied Research Limited, Toronto, Canada. The RΘ-DR System was designed for use in high-speed, all-weather aircraft engaged in long-range patrol and interception activity. As it is independent of radio aids, it is particularly useful when such aids are lacking or when radio silence is imposed. Accuracy of the present instruments is three per cent; that is, errors do not exceed three miles per hundred.

THE ROLE OF DEAD RECKONING IN AIR NAVIGATION

The navigator of an aircraft is asked to answer two main questions, namely:

1. Where are we?
2. What must we do to reach our destination?

The answer to the first question may be obtained in two general ways: by observation and by calculation. By observation is meant all methods which obtain the present position of the aircraft without reference to its past history. These include direct visual observation, and fixes obtained by radio, radar, astro-navigation techniques, or other means. By calculation is meant the derivation of present position from the knowledge of a previous position, subsequent ground speed and track, and the time interval. This technique is known as deduced or "dead" reckoning.

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Track, the direction of travel over the ground, is the sum of aircraft magnetic heading, local variation, compass deviation, and wind drift. Ground speed is the resultant of true air speed and wind speed. The determination of these quantities, and their use in solving navigational problems, was originally carried out by plotting board techniques.

Dead reckoning by itself came into early disrepute mainly because of the difficulty of obtaining accurate data to work with. All the input quantities, true air speed, true heading, and especially wind were hard to determine precisely and as a result frequent checks of position by observation were necessary. As flights became longer, and higher, and took place at night, over water, or under poor visibility conditions, direct observation of the ground became less and less practical and a great deal of effort was expended in the development of various radio devices which would either establish position or enable a pilot to maintain a desired track.

Wartime conditions, however, often imposed the need for radio silence. Astro methods were therefore revived and developed into a very useful tool in spite of their inherent slowness. Radar techniques finally provided a solution which was satisfactory in most respects, but which was still subject to many of the limitations of more conventional radio devices.

Through all this development dead reckoning held its place, partly as a standby in case of failure of the other methods, but mainly because, even when the other methods were available, dead reckoning still had to be resorted to in obtaining an answer to Question 2, "What must we do to reach our destination?" With its help, successive fixes could be used to obtain new wind information, and this could be used to calculate a new and better heading and to revise the estimated time of arrival.

EARLY AUTOMATIC DEAD RECKONING INSTRUMENTS

The continued importance of dead reckoning was recognized by the development and introduction during the war of instruments which automatically integrated aircraft velocity and displayed position. System accuracy was improved by the development of more precise instruments to supply heading and airspeed data. These navigation computers employed the same basic data



Figure 1.
RΘ-DR Computer system

as the navigator used in his plotting-board techniques, and could carry out integration of equal accuracy without needing much attention. Some of the computers took wind into account, others did not. Most of them were designed to supply aircraft position in X-Y co-ordinates, that is, in latitude and longitude. Plotting operations were still necessary to obtain steering instructions, and these had to be transferred verbally to the pilot.

THE RΘ-DR COMPUTER SYSTEM

The RΘ-DR System takes into account the effect of wind and is, therefore, a ground position indicator. It computes ground position in polar co-ordinates, and displays this information as range (three-figure counter) and bearing (pointer) from base or destination. Concentric with the bearing pointer is a second pointer which displays track, so that the pilot can home to his destination merely by adjusting heading to align these two pointers.

A general view of the instruments of the system is shown in Figure 1, and a signal-flow diagram in Figure 2. As shown in this diagram, true air speed and magnetic heading enter the Ground Speed Computer as electrical signals, and variation, wind speed and wind direction are

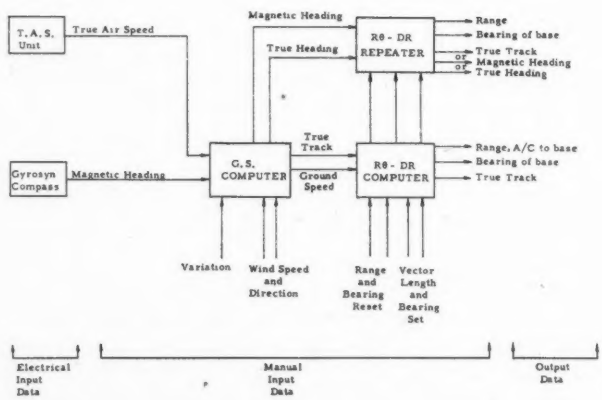


Figure 2.
Signal flow diagram, RΘ-DR Computer system

set in manually by the navigator. The G.S.C. carries out a continuous solution of the triangle of velocity; that is, adds the air speed and wind speed vectors to obtain the resultant ground speed vector, and provides true track and ground speed as electrical signals. The RΘ-DR Computer processes track and ground speed data so as to determine at all times the aircraft's ground position,

and displays range, bearing and track. Controls for adding arbitrary vectors, and for resetting range and bearing, are also located on the face of this instrument.

The RΘ-DR Repeater, intended for the pilot of a multi-seat aircraft, displays the same range, bearing and track data as the RΘ-DR Computer. A switch permits the selection of compass heading and true heading as alternatives to track.

The general character of the Computer and Repeater presentations is indicated in Figure 3, which illustrates the manner in which the aircraft position and homing data are displayed in a simple case.

In addition to its role as a navigation computer the RΘ System can be used as an Interception Computer. Provision has also been made for coupling to other equipment to increase its usefulness. In particular, it could be monitored by equipment producing outputs of drift and ground speed in such a fashion as to automatically set up wind velocity. This can currently be provided optionally without adding to the volume of the system.

Coupling to an autopilot to provide automatic homing is also a possibility. The various modes of operation with their inputs and outputs are tabulated below:

Mode	Manual Inputs	Automatic Inputs	Standard Outputs	Optional Outputs
Navigation	Magnetic Variation Wind Direction Wind Speed	True Air Speed Magnetic Heading	True Track True Bearing Range True Heading	Autopilot Coupling Ground Speed Drift
Monitored Navigation	Magnetic Variation	True Air Speed Magnetic Heading Drift Ground Speed	True Track True Bearing Range True Heading	Autopilot Coupling Ground Speed Drift
Interception	Magnetic Variation Enemy Air Speed Enemy Heading	True Air Speed Magnetic Heading	Interception Heading Range and Bearing of Moving Target	Closing Speed Lead Angle

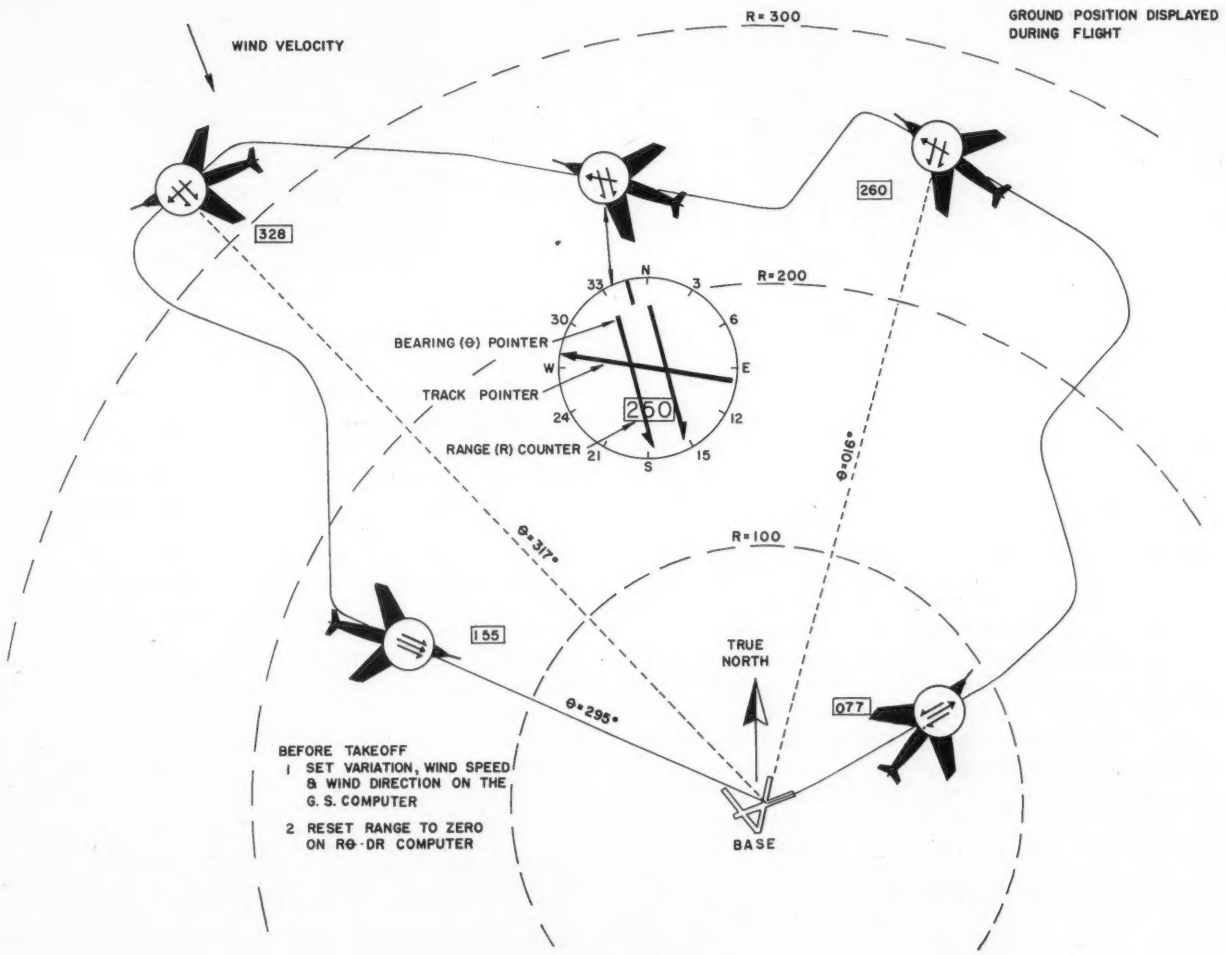


Figure 3.
RΘ Display homing operation

The instrument is basically a plane trigonometry computer but works as a quasi-spherical computer by incorporation of spherical convergency with the variation correction on the polar overlay map. This is the conventional process of grid navigation. As great circles are nearly straight lines on the overlay map the computer becomes effectively a great circle computer.

The system has no geographical limitations except as imposed by the Magnetic Compass. With a suitable Gyro Compass it can work equally well anywhere. The system is at present limited to a ground speed of 1400 knots, but the RΘ Computer has been operated on the bench at speeds of 5000 knots.

With correct winds set, flight tests have given accuracies of two to three miles per hundred miles flown.

The volume and weight of the two panel instruments are 610 cu. in. and 22 lb., but provision has been made for them to be subdivided into panel-mounted and remote units. A pilot's repeater is available for twin seater aircraft. A combined amplifier unit and system junction box of 10 lb. completes the system.



Figure 4.
Ground Speed Computer

The air speed vector is defined by true air speed and true heading. True air speed is measured by an instrument which accepts as inputs static pressure, impact pressure, and outside temperature.

True heading is provided by a directional gyro. This device is normally slaved to magnetic north, but may be free for use with appropriate grids.

Both true air speed and compass data enter the G.S.C. as synchro signals, which are followed up by conventional a-c servomechanisms. The incoming compass data is fed through a differential synchro, positioned by the variation knob, which introduces variation and therefore causes the servo to produce true heading as its output quantity.

The wind vector is introduced by the manual setting of the wind speed and wind direction controls.

Ground speed is produced as a proportional d-c voltage, and drift as a synchro signal. The former is integrated to provide ground miles; the latter is added to true heading to provide track. These quantities are transmitted to the RΘ-DR Computer.

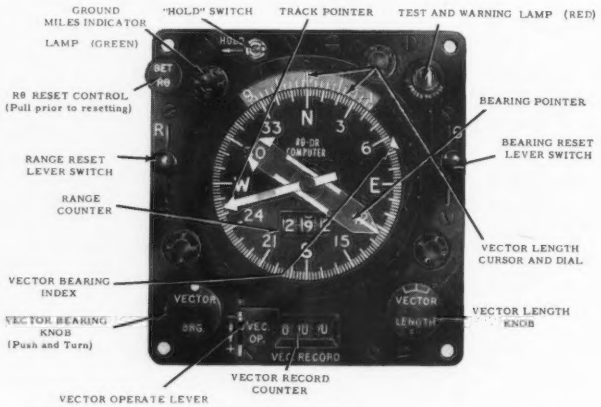


Figure 5.
RΘ-DR Computer

THE GROUND SPEED COMPUTER

Figure 4 is a front view of this instrument and shows the controls, dials, and indicators.

The Variation Knob, labelled VAR, with its index reading against the outer dial, permits the manual setting of either magnetic or grid variation over a range of from 120 degrees west to 120 degrees east. Deviation, if known, can be added algebraically to variation to eliminate all errors in the computation of true heading. On long flights, variation needs occasional adjustment.

The Wind Direction Knob and its associated pointer permit the manual setting of wind direction expressed as an angle measured from true north. The Wind Speed Crank and associated counter permit the manual introduction of wind speed.

The True Air Speed Dial is driven by a servomechanism to display the information entering from the TAS Unit.

G.S.C. COMPUTER TECHNIQUES

The G.S.C. contains a mechanical analogue of the velocity triangle. The sides of this analogue triangle represent the air speed vector, the wind speed vector, and the resultant ground speed vector.

THE RΘ-DR COMPUTER

The RΘ Computer, shown in Figure 5, carries two concentric pointers read against a compass rose, inside which is a counter. These three present the three outputs of the computer: Bearing (double pointer), Track (single pointer) and Range (counter).

The bearing pointer indicates the direction of base by the end with the arrows. The reciprocal of this, namely the bearing of the aircraft from base, is normally read at the tail end. This latter figure can be compared directly with the bearing as read from a polar co-ordinate map centred at base.

The range counter indicates straight-line distance from aircraft to base, and together with the bearing pointer it completely identifies aircraft position.

The track pointer shows the current true direction of aircraft travel.

Surrounding the compass rose are a number of knobs, switches, and indicator lamps, whose functions will be described in a subsequent paragraph.

PRINCIPLES OF COMPUTATION

From the Ground Speed Computer, the RΘ Computer accepts Track (T), and Ground Speed (S) as

inputs, and converts these into Range (R) and Bearing (Θ) as outputs. The equations connecting these quantities, which are derived in Appendix I, are as follows:

$$R = R_0 + \int_0^t S \cos(\Theta - T)\, dt \qquad \text{.....(1)}$$

$$\Theta = \Theta_0 - \int_0^t \frac{S \sin(\Theta - T)}{R}\, dt \qquad \text{.....(2)}$$

The computer solves these by means of a mechanical analogue in which S is represented by a shaft speed, while T, Θ and R are represented by shaft positions. The basic computing elements are three ball disc integrators, two sine cranks, one differential, and one lead screw, arranged as shown in Figure 6.

The track input from the G.S.C. is fed into the left side of the mechanical differential while computed bearing is fed into the right side. The output, $\Theta - T$, sets the shaft position of the mutually perpendicular sine cranks.

The ground speed input is fed to the discs of both integrators 1 and 2. These integrators with the sine cranks constitute a resolver and the output speeds of the two cylinders will accordingly be:

$$W_1 = S \cos(\Theta - T) = \frac{dR}{dt} \qquad \text{.....(3)}$$

$$W_2 = -S \sin(\Theta - T) = R\frac{d\Theta}{dt} \qquad \text{.....(4)}$$

The shaft position of cylinder 1, a_1, representing the time integral of (3) is:

$$a_1 = \int_0^t \frac{dR}{dt}\, dt = R - R_0 \qquad \text{.....(5)}$$

in which R_0, the constant of integration, represents an initial condition. The output of integrator 1 is therefore connected directly to the range counter and to the range lead screw. The nut on this lead screw positions the ball carriage of integrator 3 so that its displacement from center is proportional to R.

As the cylinder of integrator 3 turns with that of integrator 2 according to Eq (4), the disc of integrator 3 turns at the rate

$$W_{D3} = \frac{d\Theta}{dt} \qquad \text{.....(6)}$$

Thus the shaft position of this disc, representing the time integral of (6), is given by

$$a_{D3} = \Theta - \Theta_0 \qquad \text{.....(7)}$$

This shaft drives the bearing pointer and, as mentioned above, the right side of the differential.

TECHNIQUES OF COMPUTATION

In principle, the arrangement so far described is capable of performing the RΘ computation, but in practice, electrical elements must be added for two reasons, namely: data frequently have to be transmitted between units which cannot be mechanically connected, and torque multiplication must be used so that comparatively heavily-loaded shafts may be moved by devices which are capable of producing only very limited torque outputs.

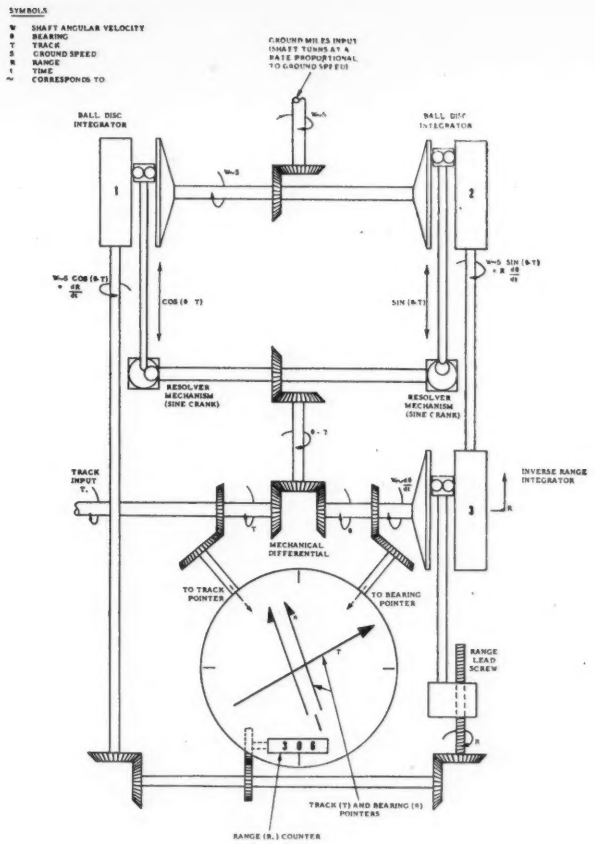


Figure 6.
Elements of RΘ Computer

In the case of the track input from the G.S.C., these two functions are combined in a conventional synchro-control transformer circuit such as has already been referred to in the Ground Speed Computer. In the case of the ground speed input the two functions are separated and both are performed by d-c devices having discontinuous outputs. The d-c data transmitter consists of a rotating segment switch turned by a shaft at the source of the data which energizes a Desynn motor at the receiving end. This motor has a three winding stator and a permanent magnet rotor which, due to the limited resolution of the stepping switch, moves in 30° steps. Such a system can only be used, of course, where this amount of angular rotation represents an acceptably small amount of data.

Torque multiplication is carried out by means of a d-c device consisting of a lead screw differential operating a contactor. The type shown in Figure 7 and described here is suitable for bi-directional operation. The low torque shaft turns a lead screw which shifts the nut from its central position and closes one of the sets of contacts. This energizes a d-c motor which, through the drum gear, drives the nut back to its central position, thus opening the contacts and cutting off the motor. The output is thus discontinuous but equal in total to the input. The low torque shaft produces only enough torque to move the nut on the lead screw while the

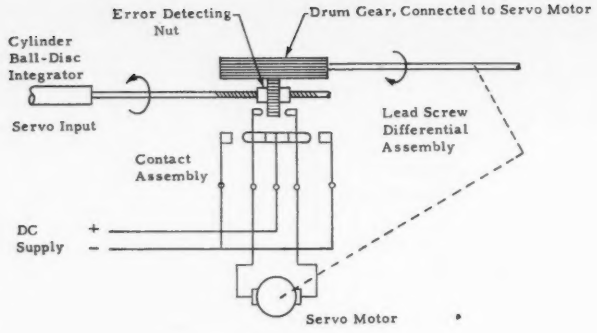


Figure 7.
Bi-Directional contactor servo

motor provides the torque to drive the load. If the input shaft changes direction the nut moves in the opposite direction, closes the other set of contacts and energizes the motor with voltage of reversed polarity. Thus, as before, the nut is driven back towards its central position. The use of such devices, which eliminate the need for electronic amplifiers, is a feature of this computer.

SPECIAL FEATURES

The above section has discussed the equipment necessary for the functioning of the RΘ Computer in its fundamental role as a homing device. In this simple form it would have a comparatively limited value. The following section will describe the additional features which greatly increase its operational flexibility.

RESETTING OF RANGE AND BEARING

The reset facility, provided by the reset lever switches on either side of the dial in conjunction with the RΘ reset control, permits either range or bearing or both to be adjusted at will. Resetting is accomplished by means of the same motors which are used to drive the range and bearing servos during normal operation. The motor in question is disconnected from its normal service both mechanically, by a clutch, and electrically by the lever switch. The same switch connects the motor across the line in either sense as desired to drive the counter, or pointer, to the required value, and at the same time to reset the associated internal computing elements. Limit switches are provided to cut off the range motor at zero and approximately 1,000 miles, but continuous rotation is permitted in the bearing circuit.

The usefulness of this reset feature may best be understood by considering the fundamental Eqs (1) and (2) for range and bearing presented above. In these equations, R_0 and Θ_0 appear as constants of integration. They represent the values of R and Θ at the time of starting the computation. If the flight is to return to the point of take-off, the range could be set initially to zero at which range the bearing is indeterminate. Action of the bearing pointer under these conditions is discussed under Automatic Reciprocal. If, however, it is intended to go to some other destination, the range and bearing of the point of take off, as seen from the destination, may be set. If an observed position shows the computer readings to be in error, range and/or bearing may be adjusted to the correct values and the computation restarted from that point with the error removed.

GROUND MILES MEMORY

Under some conditions it becomes desirable to suspend computer operation temporarily, as for example, if a fix is obtained at a time when it is inconvenient for the operator to check the computer reading. When time permits he can compare computed and observed positions and reset if necessary. While computation is suspended, incoming ground miles must be stored in a memory device so as to be available when computation is resumed. The hold switch provides these features.

VECTOR ADDITION AND SUBTRACTION

The process of vector addition is the means by which the operator can choose a different base from the one originally set on the computer. The method by which this is done may be understood from a study of Figure 8 in which A represents the aircraft, O the base from which it is operating, and B the desired alternate base.

Then Vector OA = range and bearing of A from O
= present indication of computer
Vector BA = range and bearing of A from B
= desired indication of computer

Vector BA can be derived from OA by adding the vector BO, i.e. $BA = BO + OA$.

This vector BO is, of course, the bearing and distance of O from B and can be determined from a map or from a prepared table. The operator carries out a vector addition as follows:

(a) Set Vector Bearing (direction of OB) by turning the Vector Bearing Knob.
(b) Set Vector Length (length of OB) by turning the Vector Length Knob.
(c) Press the Vector Operate Lever down and release.

The addition is carried out by the computer as follows:

(a) The track servo adopts the track which corresponds to the bearing of O from B. Actually OB is set but the computer produces the reciprocal BO.
(b) The ground miles servo motor drives at full speed until it has fed in an amount equal to the distance from O to B.

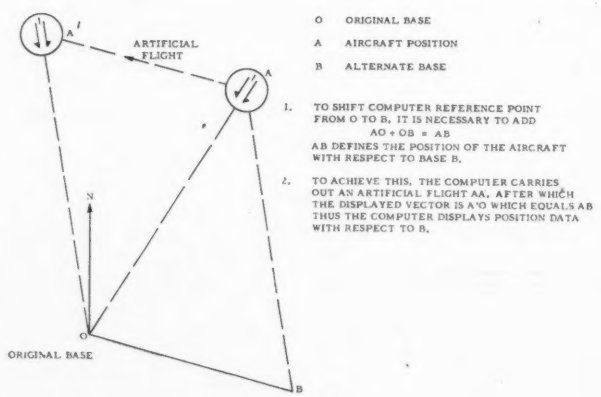


Figure 8.
Vector addition

That is, the computer is made to act as if the aircraft had turned and flown at a very rapid rate (about 50,000 knots) from A to A^1. During this "flight", the displayed range and bearing change from the values defining the vector OA to these defining OA^1 which equals BA. After this operation has been completed, the track servo returns automatically to its usual role of repeating aircraft track, and normal computer operation proceeds with B as base.

VECTOR SUBTRACTION

This process permits the removal of the last vector added in without having to reset the instrument. It is performed by lifting rather than pressing the actuating lever. Once a vector has been set on the computer it may be added and subtracted as often as desired without new settings. This technique is particularly useful when the computer is being used in conjunction with maps carrying polar co-ordinate overlays as described below, in the section on Operating Techniques.

AUTOMATIC RECIPROCAL

While computation in polar co-ordinates has many advantages, it presents certain technical problems which must be overcome. Probably the most serious is concerned with operation very close to base, where even at low ground speeds the rate of change of bearing becomes very great. Obviously there must be some practical limit to this rate beyond which the computer cannot function. In this computer a circle has been created with an arbitrarily chosen radius of two miles around base inside which normal action of the bearing servo is replaced by a special operation. When the two mile range is reached the bearing pointer automatically moves to the same value as track and hunts about this value. This is the position in which bearing remains constant while range decreases. When range reaches zero the bearing pointer turns through 180° to the reciprocal of track and hunts about this value. Range now increases until, at two miles, normal operation is restored.

The whole process is closely analogous to bearing reset except that it is initiated automatically and that operation of the ground miles and range circuits is not suspended. If the flight is not directly over base a small error, usually less than one mile, may be introduced.

GROUND MILES RETARD

From the above discussion it will be obvious that the high speeds used in vector addition and subtraction create very serious problems for the bearing servo. In fact it has proven completely impractical to design a bearing servo which will operate at these speeds down to the range of two miles. The problem has been overcome by a device known as the "Ground Miles Retard" by means of which the high, fictitious ground speed is automatically reduced whenever either the range or bearing motor reaches its maximum speed. Both servos were designed to handle speeds of up to 2,000 knots under all operating conditions, so that this feature does not come into play except during vector add or subtract.

OPERATING TECHNIQUES

Operating techniques for the RΘ-DR System are undergoing continual improvement as experience with the equipment is gained. This section and the two which follow describe in detail the techniques that may be employed in typical situations.

1. The RΘ-DR System as a Simple Homing Aid

The most elementary and perhaps most used application of the system is as a homing aid on flights from and back to base. This situation was depicted in Figure 3.

When the aircraft power supplies are switched on, the RΘ-DR System begins to operate. After a preflight check, the navigator will

(a) Set variation on the G.S.C.
(b) Set forecast wind on the G.S.C.
(c) Reset range to zero in these steps:
  (i) Pull the set RΘ knob.
  (ii) Depress the range reset switch. Range will automatically stop at zero miles.
  (iii) Restore the set RΘ knob.

In the zero range state, the bearing pointer adopts the angle of the track pointer, indicating base to the rear, and hunts about that position. As the aircraft takes off, flight computation ensues.

No further action by the navigator is necessary during the flight, although additional steps may be taken if desired. For example, fix data may permit resetting range or bearing, or adjustment of wind information. To use fix data in this type of operation, a map must be available carrying polar co-ordinates with the origin at the aircraft's base. Alternatively, if the navigator can obtain range and bearing data from a radio aid at his base, such information can be used to check the RΘ-DR Computer.

After tactical objectives are realized, the pilot, without necessarily referring to the navigator, changes the aircraft heading to line up his track pointer with his bearing pointer. In this condition the aircraft homes directly to base. When computed range is reduced to zero, the aircraft should be well within the range of local radio aids.

2. Homing Flight From Base *A* Diverted to Base *B*

If, during a flight, it becomes necessary to land at an alternate base B, rather than the take-off point A, the vector from A to B must be added en route. In the example to be discussed, shown in Figure 9, the vector to be added is 280 miles long at an angle (to true north) of 290 degrees. These values may be set up on the RΘ-DR Computer at any time before or during the flight. When the decision is taken to shift base, at position 3, the vector operate lever is pressed to add vector AB. After this operation is completed, at position 4, the computer displays homing data relative to base B (positions 5 and 6) for the remainder of the flight. The pilot homes to base B by altering the aircraft heading so as to align the pointers, and flies until range indicates zero. Should the decision to land at base B be reversed, vector AB can be erased merely by lifting the vector operate lever. The reference point of the computation will revert to base A, to which the pilot may home by aligning the pointers as before.

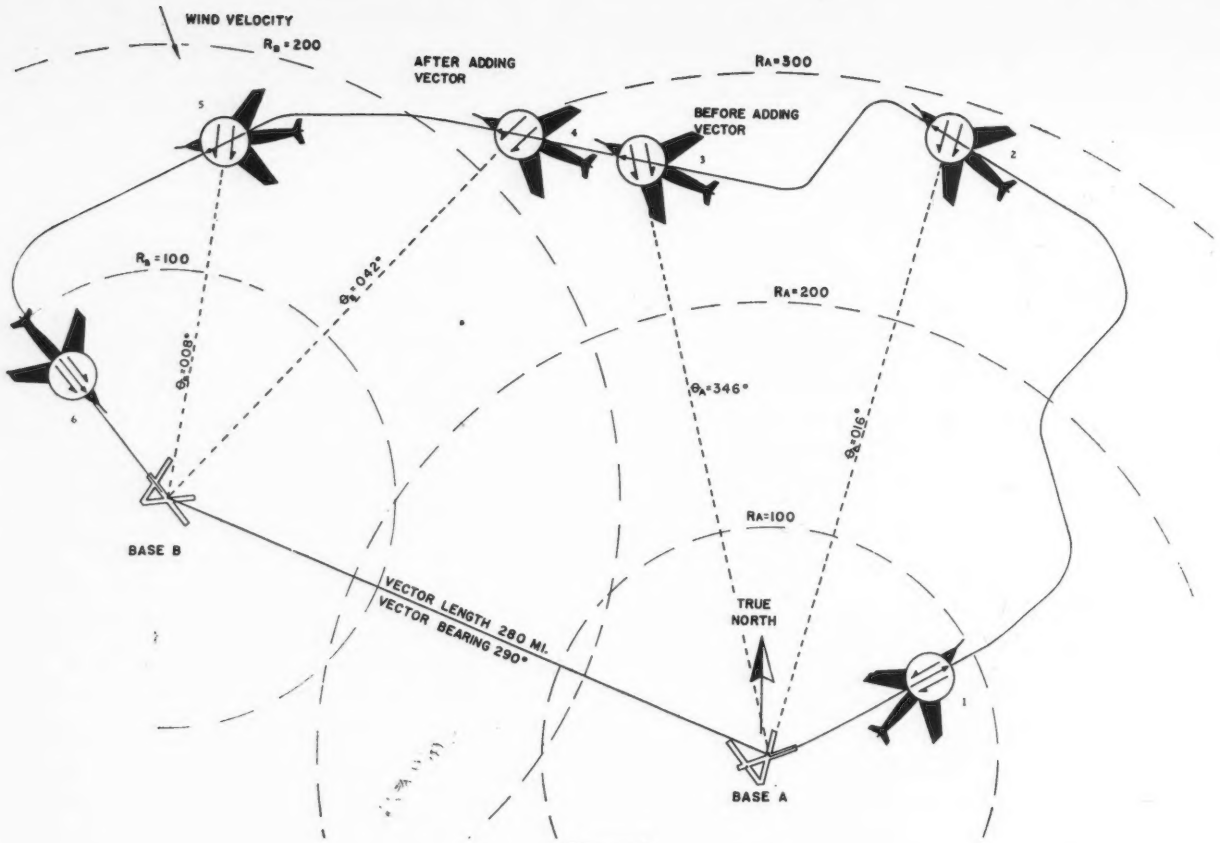


Figure 9.
Homing flight diverted to alternate base

If advantage is to be taken of fix data while computation is based on *B*, a polar grid with origin at *B* is needed. This may be provided on a separate map, or as a transparent overlay which could be placed and oriented at any selected point. To avoid the need for carrying several maps, or overlays, standard maps have been overprinted with polar co-ordinate grids, with origin at the map corner. Any point on the map can readily be identified in terms of range and bearing from this grid origin. Thus, if during the flight the computer reference point is set at the grid origin, any fix obtained can be directly compared with computed position, and corrections made if needed. Homing to any point on the map may then be carried out by adding in the vector which identifies the grid position of the required destination, and aligning the track and bearing pointers.

With this technique, an aircraft can proceed to any number of objectives in succession. As a given objective is reached, by homing, its position vector is erased. The reference point shifts back to the map corner. The position vector of the next objective is set up on the vector add controls, and added in. Thus the reference point shifts to that objective and the pilot homes to it by aligning pointers.

As the information needed to set up a destination is merely the position vector of that point with respect to grid origin, a wide variety of alternatives can be provided on a table of vectors. No advance selection of the destinations to be chosen need be made.

The vector add and subtract feature which is so useful in changing base has many additional applications. In fact, because of this feature the computer can be used to carry out any of the operations normally done by plotting, as, for example, wind finding, and obtaining average wind during a climb.

CONCLUSIONS

The RΘ-DR Computer System represents a significant advance over earlier equipment in these respects:

(1) The two main questions to which the navigator must reply are answered by a single display. That is, steering information is explicitly provided by the position data.

(2) The unique method of computation minimizes the number of computing elements required, thereby tending to reduce error. This method also permits adjustment of range and bearing values directly.

Although the system was designed to be independent of radio aids, it can be used in conjunction with them. When they are available, radio aids can act as an occasional monitor for the dead reckoning computer by providing periodic fixes against which to check the computation.

The RΘ-DR System provides automatic navigation of sufficient accuracy to enable an aircraft to approach its destination to within range of local radio aids. As such, it fulfills a definite need in long range navigation.

APPENDIX A

MATHEMATICS OF RΘ COMPUTATION

The equations which form the basis of this computation are stated in Figure A.1. These show that the resolving angle is the difference between bearing and track. The radial and circumferential components of velocity are derived from ground speed and the resolving angle. The calculation of bearing rate involves a division by range. It is this division which necessitates the automatic reciprocal operation at very low ranges.

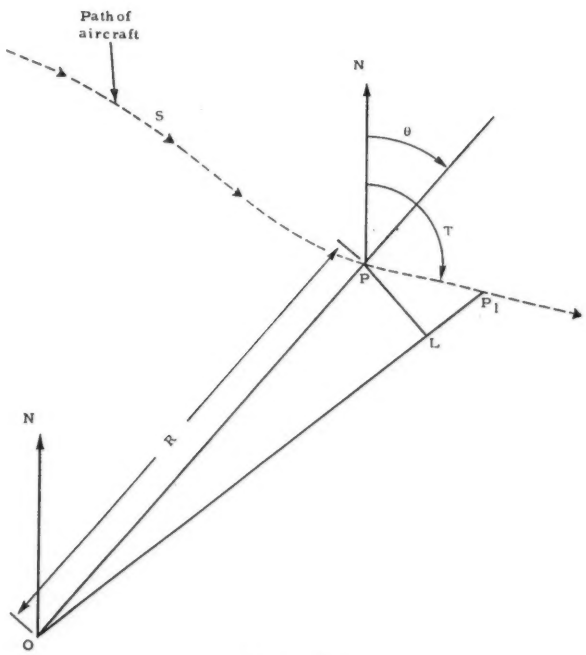


Figure A.1.
Mathematics of RΘ computation

Symbols

O	Base position
P,P_1	Successive aircraft positions.
S	Ground speed.
N	True north.
T	Track (true).
Θ	Bearing (true), aircraft from base.
R	Distance, aircraft from base.
R_0, Θ_0	Initial values of R, Θ.
t	Time.

Derivation of Equations

PP_1 represents the small distance travelled in the interval of time dt.

Thus $PP_1 = Sdt$

In the small triangle PP_1L,

$$LP_1 = Sdt.\ \sin P_1PL = dR$$

and $PL = Sdt.\ \cos P_1PL = Rd\Theta$

now $P_1PL = 90° + (\Theta - T)$

thus $dR = Sdt.\ \cos(\Theta - T)$

and $Rd\Theta = -Sdt.\ \sin(\Theta - T)$

whence $$R = R_0 + \int_0^t S\cos(\Theta - T)\,dt$$

$$\Theta = \Theta_0 - \int_0^t \frac{S\sin(\Theta - T)}{R}\,dt$$

INSTRUCTIONS TO CONTRIBUTORS

The Canadian Aeronautical Institute invites the submission of papers, articles and technical notes for publication in the Canadian Aeronautical Journal. Following the practice of other societies, the Institute does not pay for contributions.

Authors should prepare their material in accordance with the following directions:

Manuscripts. Manuscripts should be
(a) Typewritten, double-spaced,
(b) On one side of 8½ x 11 white paper,
(c) With wide margins, approximately 1½", and
(d) With pages numbered consecutively.

Manuscripts must be in final form; the addition of material after acceptance by the Institute cannot be permitted.

Titles. The following form should invariably be adopted:–
(a) Titles should be brief;
(b) The name and initials of the author should be written as he prefers; (Rank or title preceding the name e.g. Wing Commander or Dr., should be included but abbreviations of degrees etc., after the name, should be omitted.);
(c) The name of the organization with which the author is associated should be shown under his name; and
(d) The author's position in the organization, referred to in (c) above, should be shown as a footnote to the first page.

Summaries. Each paper should be preceded by a summary
(a) Of 100 to 300 words, (10 to 35 lines, double-spaced),
(b) In non-specialist language, so far as possible,
(c) Stating the main conclusions of the paper.

Sub-Headings and Paragraph Numbering. Sub-headings should be inserted by the author at frequent intervals. Paragraphs should not be numbered.

References. References referred to by the author should be treated thus:–
(a) References should be numbered consecutively throughout the paper;
(b) An allusion to a reference should be indicated by a bracketed numeral e.g. "It has been shown by Dr. T. T. James (7) . . . ";
(c) Direct citation of a reference in the text should be written in full, e.g. "As shown in Reference (7) . . . "; and
(d) References should be grouped together in numerical order at the end of the paper, each showing
first, the numerical designation, e.g. "(7)".
second, the author's name, e.g. "James, T. T."
third, the title of his work, e.g. "Aerodynamics and Ballistics"
fourth, the title, volume, issue no, and date identifying the publication in which it appeared, e.g. "R.B.S. Journal, Vol. 7, No. 77, July 1907".

Thus "(7) James, T. T.,–Aerodynamics and Ballistics, R.B.S. Journal, Vol. 7, No. 77, July 1907."

Footnotes. Comments on or amplification of the text should be given in footnotes, appearing at the bottom of the appropriate pages.
(a) Footnotes should be designated alphabetically and consecutively throughout the paper; and
(b) A reference to a footnote in the text should be indicated by a bracketed letter, e.g. "omitting consideration of the third power (c) . . . "

Figures, Tables and Equations. Reference in the text to
(a) Figures and Tables should be given in full, e.g. "Figure 7", but
(b) Equations should be abbreviated to Eq., e.g., "Eq.(7)" or "Eqs.(5) and (6)".

Drawings. Drawings should be
(a) Individually identified by Figure or Table number,
(b) Not larger than 12" x 16",
(c) In black ink on white paper or tracing cloth, and
(d) Capable of being reduced to 3½" wide without loss of legibility of lettering or other detail.

Photographs. Photographs should be
(a) Black and white, glossy prints, and
(b) Individually identified by Figure number, written on a separate piece of paper affixed to the back: writing on the back of the photographs should be avoided.

Captions. Each Figure and Table should be identified by a caption, in addition to its number, e.g., "Figure 12 Theoretical lift distribution".
(a) The caption of a Table should be shown at the top of the Table;
(b) The caption of a Figure should be shown preferably outside the boundary of the Figure; and
(c) A complete list of Figure and Table captions should be given on a separate sheet of the manuscript.

Mathematical work. Only the simplest mathematical expressions should be typewritten; others should be carefully written in ink. Mathematical work should be
(a) Uncrowded–plenty of space should be provided to accommodate directions to the printer–,
(b) Repeated on a separate sheet of the manuscript, again uncrowded and with plenty of space around each expression,
(c) Clearly written to distinguish between like symbols. e.g. between zero and the letter 'o', and between Greek and English letters of similar form, and
(d) Accompanied by a manuscript "index" of the Greek letters used in the paper, identifying each letter by a name, e.g. "α–alpha".

In addition the following practices should be adopted:
(a) Simple fractions appearing in the text should be shown with a solidus, e.g. A/(B+C) rather than as

$$\frac{A}{B+C}$$

(b) Complicated expressions should be identified by some convenient symbol, if necessary to avoid repetition of the whole expression; and
(c) Complicated subscripts and exponents, and dots and bars over letters or symbols should be avoided.

Symbols and Abbreviations. Consistency is important;
(a) The symbols recommended in the American Standards Association "Letter Symbols for Aeronautical Sciences" ASA Y10-7–1954 should be used wherever practicable; and
(b) Abbreviations of units should be shown in lower case without periods, e.g. lb, mph, bhp, etc.

Mailing. Papers should be mailed to The Secretary, Canadian Aeronautical Institute, 607 Commonwealth Building, 77 Metcalfe St., Ottawa 4, Canada.
(a) Drawings and photographs may be mailed rolled or flat, not folded;
(b) Manuscripts should be mailed flat.

C.A.I. LOG

SECRETARY'S LETTER

THE timing of this issue of the Journal is unfortunate. As it goes to press, the joint I.A.S/C.A.I. meeting is yet to take place but, by the time the Journal is in the hands of our members, the meeting will be over by some two weeks and everybody will be half expecting to read about it. I can only advise you to look forward to the December issue, in which the meeting will be fully covered.

NEW HEADQUARTERS

We moved into our new Headquarters on the 15th October. The plaster was scarcely dry and even now the place has not been painted but at least we can settle in, with a certain amount of elbow-room.

The new premises consist of two rooms, one serving the dual function of Council Room and my office, and the other occupied by Mrs. Ross and Miss Grant with the files, etc. We are on the sixth floor of the new Commonwealth Building which is quite centrally located (on Metcalfe and Albert) and I hope that any members visiting Ottawa will take the opportunity to visit us.

STUDENT SECTIONS

Student Section activities are important to the healthy growth of the Institute but in the past we have been so busy with other things that the organization of our Student members has not received very much attention. The Toronto Branch gave some thought to the problem last spring and set up a Section to serve the special interests of the Students within the over-all pattern of the Branch.

I learn now that there are stirrings at Royal Roads, which may develop a Student Section of the Vancouver Branch.

I am sure that there are other places in Canada where Student activities should be encouraged and where they could, in some districts, represent the major part of Branch activities. One thing seems certain; no two Student Sections can function in the same way and each will depend on local arrangements to suit local circumstances. For this reason I feel that we are somewhat in the hands of the members on the spot; we cannot purvey ready-made Student schemes from Headquarters. Any member living within reach of some suitable student body, might turn the problem over in his mind and if he has any ideas he might write to me about them. He can be sure that Headquarters will help, but Headquarters cannot very well initiate.

LIST OF MEMBERS

In the near future—I hope before the end of October—cards will be sent out to all members asking for a few particulars which will be used to prepare a membership roster. Publication of a List of Members is long overdue.

When a List of Members has been issued we propose to publish, in the Journal, lists of new members as they are admitted. These periodic lists will in effect constitute amendments to the List of Members. Once a year the full List will be brought up to date and reissued. If we can follow this plan we will provide all our members with a useful and interesting directory of their colleagues engaged in Canadian aviation.

Members are asked to cooperate in this project by completing their cards and sending them in promptly. Some members who happen to live abroad may find that they are unable to send their cards in by the specified date, the 3rd December; this should not deter them from sending them in anyway.



BRANCHES

NEW BRANCH

Edmonton

THE Council has approved the formation of a Branch at Edmonton. The membership in that city has been gradually growing under the guidance of an Interim Committee consisting of Mr. C. C. Young and W/C J. G. Portlock and it now amounts to 32 members.

An election will be held soon to decide the Officers and Councillors who will take over the administration of the Branch from the Interim Committee.

POTENTIAL BRANCHES

Last year, in addition to the existing Branches at Toronto, Ottawa and Montreal, provisional organizations were set up in certain other cities where interest in the C.A.I. seemed to be growing. In each case some member volunteered to act as "Interim Secretary", to provide a local contact with Headquarters, to hand out application forms and generally to serve as a nucleus for the movement in his district; he was not asked to do any active promotion of membership and he was not held in any way responsible if the results proved to be disappointing.

From such beginnings full scale Branches have been built up in Vancouver and Winnipeg; and, as recorded above, the group of members in Edmonton has recently attained Branch status.

Development has not been so rapid in Calgary and Halifax. The Interim Secretaries in these two cities are

Calgary—Mr. W. E. Jamison,
2002 - 25A St., S.W.,
Calgary, Alta.

Halifax—Professor O. Cochkanoff,
Mechanical Engineering Dept.,
Nova Scotia Technical College,
Halifax, N.S.

Members visiting Calgary or Halifax are urged to get in touch with the Interim Secretaries, just to let them know that the C.A.I. in general appreciates their vigil, and to acquaint them with Branch activities elsewhere. Furthermore, in their own interests, members living in these cities should keep in touch with their Interim Secretaries and do what they can to encourage their friends to apply for membership; in both cases only a few more members are required to attain the requisite minimum (20) for the formation of a Branch.

In addition to the provisional or "Interim" organizations at Calgary and Halifax, there is evidence of growing interest in Quebec City; a few enquiries have been received but no one has yet offered to serve as Interim Secretary.

NEWS

Ottawa—Reported by Dr. A. Jaworski

October Meeting.

The second meeting of the 1955/56 season of the Ottawa Branch was held at the Beaver Barracks on the 12th October. Mr. J. L. Orr, Chairman of the Branch, presided.

The Chairman opened the meeting with a reminder to the members that the joint I.A.S./C.A.I. Meeting is to be held this year in Ottawa. He expressed the hope that all members of the Branch would attend, and would maintain the high standard of hospitality which had been displayed at previous Institute meetings by the Montreal and Toronto Branches. The Chairman also drew attention to a letter received from the Secretary of the Institute about members being in arrears with their dues. He then called on Mr. C. D. Long to introduce the speaker.

Mr. Long commented that introduction in this case was rather superfluous not only due to the fact that the speaker, G/C H. R. Foottit, occupied a prominent position among the R.C.A.F. engineering staff, but also because he was known to all members for his activities in establishing the Institute.

G/C Foottit's subject was "The Time Factor in Aircraft Development". From the fund of statistical information which had been gathered, the speaker was able to show comparatively by means of charts, the times required to develop various types of aircraft—jet trainers, small and large transports, and jet fighters and bombers—and from R.C.A.F. experience with the CF-100 he was able to quote a specific example. Starting from the date of issue of the specification, the speaker considered the design and development phases up to the point at which aircraft are delivered meeting the specification requirements, a period averaging from 4 to 9 years depending on the type. He studied the phases and sub-phases, occupying the over-all period and mentioned some of the measures, such as the ordering of several prototypes and the specialization of aircraft contractors, which had been adopted in recent years in an endeavour to speed up the process. He also suggested other contractual devices which might prove advantageous.

In the discussion which followed some members challenged the validity of the date of issue of the specification as a fair starting point—in view of private venture considerations and the like. Others put forward various suggestions for the reduction of the time factor, notably that more test flying might be done at night. In conclusion the speaker was warmly thanked by G/C W. P. Gouin on behalf of the members and guests present.

Approximately fifty members were present and probably the attendance was adversely affected by the fact that some of the members living outside Ottawa had received notification of the meeting very late because there was no postal delivery on Thanksgiving Day. The Executive took this fact to notice and is promising the members more advance notice of future meetings.

Vancouver—Reported by R. J. McWilliams

October Meeting

The meeting was held at the Aero Club of B.C., at 8.00 p.m., October 11th, 1955 and commenced with a business session lasting fifteen minutes. Twenty-six members and five guests were present.

Our guest speaker, Mr. Owen G. Dinsdale, Materials and Processes Engineer, C.P.A.L., was introduced by Mr. Ian Gray, C.P.A.L. Mr. Gray spoke of the training and experience of our speaker, and the timeliness of his subject "Titanium". Much has been heard in recent years of this new wonder metal, so much that one wondered why the metal itself was not in greater use. By the end of the evening we would have the answer to this, and possibly many other questions which had puzzled us in the past.

In his introductory remarks Mr. Dinsdale surveyed the history, availability and early uses of the metal. Although known and named at the end of the eighteenth century, it was the wartime necessity of one hundred and fifty years later which sponsored quantity production and focussed attention on the possibilities of the metal. Titanium is fourth in the order of availability of structural metals, is abundant in many countries, and is obtained by relatively simple mining processes. Its present high cost is due to the difficulties of processing.

Mr. Dinsdale dwelt at some length on the properties of the metal stressing the wide differences between the commercially pure and the alloyed state. He made considerable comparison with other metals, and particularly with the steel and aluminum alloys. Titanium although one and a half times the density of aluminum, has the equivalent strength of steel up to temperatures of about 800°F. He emphasized the good strength/weight ratio, strength/temperature relationship up to 800°F. and corrosion fatigue resistance. Its main disadvantages were its rapid deterioration at high temperatures due to surface contamination, and its very poor handling characteristics.

Mr. Dinsdale devoted considerable time to production methods, and handling characteristics. The problems of shaping, casting, welding, machining and riveting were each given proper attention. He discussed at some length, existing uses and possible future uses. Its limited application to date was undoubtedly due to its high cost, which was in turn due to the limited production to date, caused by the major problem of surface contamination at normal handling temperatures. However, the future is fairly bright, production by the end of next year in the U.S.A. is expected to increase three-fold to 23,000 tons per year, and as is to be expected research and development is receiving concentrated attention.

Titanium is not a miracle metal, yet it represents a tremendous scientific and production advancement. Undoubtedly its best applications have yet to be discovered and its development opens up new possibilities in the future of high speed flight. A new metal is badly needed if man is to travel at transonic speed.

The thanks of the meeting were expressed by Mr. R. N. McCollum, Sperry Gyroscope Co. of Canada Ltd. Mr. McCollum congratulated Mr. Dinsdale on the way in which he had so ably covered the many aspects of the work being done and which remained to be done. He pointed out that the present stage of development of Titanium might be likened to that of Aluminum some twenty years ago. He called to mind scepticism at that time, contrasing it with the wide spread use and our familiarity with Aluminum and its alloys today.

Then followed a very enjoyable and informal discussion period lasting a full hour. Many were the questions put to our speaker, and wide ranged the postulations and imaginings of his audience. A very satisfied group of individuals called it a day at 10.30 p.m. All present signified their approval of the type of meeting and particularly of the "jam session" form of discussion period.

Toronto—Reported by M. D. Willer

September Meeting

The inaugural lecture of the winter season was held at the Mining Building of the University of Toronto on the evening of September 7th. The speaker was Dr. D. G. Samaras, Chief of the Propulsion Research Branch, United States Air Force, Wright Air Development Centre who addressed a capacity audience on the subject of "Nuclear Propulsion".

Illustrating his points with the aid of slides Dr. Samaras first touched upon the history of propulsion from remote times to the present day. He emphasized that only since the last century has Man ceased to be dependent on beasts of the field for transportation, and yet within the last sixty years, he has developed the reciprocating engine to the practical limits of its efficiency and is fast approaching the same stage with the gas turbine engine. Dr. Samaras was of the opinion that aviation was the field in which nuclear power units were capable of most intensive development. Initially, the units would perhaps be a compromise, based upon the most advanced engines known today. Practical limitations imposed by the properties of materials presently available to build the units might in time be overcome, perhaps by nuclear transmutation—though this possibility was pure speculation.

Dr. Samaras then divided the future of aviation, like Gaul, into three parts—terrestial aviation, interplanetary travel and intragalactic travel. For terrestial aviation some form of nuclear reaction powered mass ejection engine might be suitable. For interplanetary travel nuclear rocket performance promises speeds equalling the speed of light. For intraglactic travel maybe something a little faster would be required! The optic barrier represented by the speed of light might eventually be overcome as was the so-called sonic barrier—you remember that old thing? The propulsive units necessary to travel at these velocities would be radically different from anything we have today. Touching upon the advantages and disadvantages of nuclear fusion and fission respectively as a source of propulsive power the speaker developed his opinions on the possibility of field interaction propulsion for intragalactic travel and took his audience through the fascinating field of ion flow dynamics.

A provocative and stimulating address, the lecture was followed by a question period that was ended reluctantly due to the lateness of the hour.

Dr. Samaras was warmly applauded by those present and, if they were still a little incredulous as they dispersed into the prosaic surroundings of College Street they looked a mite thoughtful—after all, look how wrong Simon Newcombe turned out to be!

October Meeting

An interesting exposition of some of the methods and media used in wind tunnel research was given before the Toronto Branch by Dr. David C. Hazen, Professor of Aeronautical Enugineering, Princeton University, on October 11th last. The occasion was the second lecture of the winter season and the venue the Mining Building of the University of Toronto.

Taking as his subject "Smoke Flow Visualization", Dr. Hazen outlined the problems of wind tunnel design and the advantages and disadvantages of numerous methods of making the effects of airflow visible. Woollen tufts attached to the body of the model, vapours of petroleums and other fluids, smokes produced by burning oil, cigars, manure—no sense of incongruity has deterred the researchers in their quest for suitable media.

One of the most effective of the media used has proved to be kerosene, vaporized by the application of heat and projected at high velocity from a battery of closely spaced jets into the airflow.

Probably the most important factor in the accurate evaluation of research results has been the development in recent years of the ultra high speed motion picture camera. Such cameras, strategically placed, can record the events of a split second from many angles simultaneously. The films can later be screened for minute and unhurried inspection and evaluation. The implications of this comparatively new technique need not be stressed.

Dr. Hazen illustrated his address by showing a selection of many films, both in black and white and in colour, taken at the James Forrestal Research Center at Princeton University. That flow

visualization is not limited to the confines of the wind tunnel was shown by a film taken in the open air on the grounds of the campus which vividly demonstrated flow effects of helicopter rotor blades.

Having seen the films one's respect for the capacity of the early designers to develop correct airfoils without the knowledge vouchsafed us by the wind tunnel and smoke flow is increased. The problems of smoke flow in supersonic and hypersonic tunnel tests present a fascinating and complex field of development.

Discussion on the various problems of smoke flow visualization followed the lecture. In conclusion we could not help but feel that, if the birds know all this instinctively, Man has still got a long haul ahead.

Montreal—Reported by
E. C. V. Norsworthy

October Meeting

The October 19th meeting of the Montreal Branch, Canadian Aeronautical Institute, was held at the plant of Bristol Aero Engines Limited. Following an excellent dinner in the plant cafeteria, a tour of the factory was arranged which was particularly interesting due to the variety of overhaul work this Company carries out. Members attending were able to follow the overhaul procedures used on Merlin 224 and 620 engines and their associated Lancaster and TML power plants, the Wright R-2600, and Turbo-Compound engines, Bristol Centaurus and Hercules engines, as well as Meteor tank engines.

Following the plant tour, Mr. John Motzer, Assistant Chief Project Engineer, Wright Aeronautical Division, Curtiss Wright Corporation, gave an interesting account of the development of the Turbo-Compound engine from the start of its development as a non-compound engine in 1942, and described the high points of the 45,000 test hours which had been carried out during the development of the engine. During this development the take-off horse power increased from 2200 to 2600 in the non-compound version and from 3100 to a maximum of 3700 which is being obtained in some military applications of the compound engine. During this development the specific weight of the engine was reduced from 1.30 lb. per h.p. to the present figure of 0.90.

Mr. Motzer described the prototype compound engine which incorporated six power recovery turbines and described how this number had been reduced to three in order to obtain better power recovery by reduction of friction and windage losses. He also described in some detail the construction of the power recovery turbine and the methods that had been developed to counteract vibration and the early troubles that had been experienced with turbine disc and nozzle box cracking.

In the question period following Mr. Motzer's talk, Mr. John Ludwigsen, Manager, Service Engineering, Wright Aeronautical Division, discussed the troubles that had been encountered with the engine on initial introduction to airline service and the steps that had been and were being taken to overcome them.

The talk was particularly interesting since the Turbo-Compound engine was or would shortly be the direct concern of a large proportion of the members present. Mr. Jim Hutton, Engineering Manager, Bristol Aero Engines Limited, in his introduction of the Speaker referred to Mr. Motzer's long experience with the basic engine, which was most evident during his talk, and Mr. Ades, Assistant Director of Engineering, T.C.A., in thanking the Speaker commented on the refreshing lack of "long hair" discussion.

Approximately 130 members attended the meeting.

BRANCH PROGRAMMES

Further particulars as follows are now available about the Winnipeg Branch programme, which was rather briefly treated in the last issue;

Winnipeg

27 SEPTEMBER
"*The Problem of the Very Light, Highly Efficient Airplane*"
B. S. Shenstone

25 OCTOBER
"*Aspects of Aircraft Selection for Airline Use*"
Clayton Glenn

29 NOVEMBER
"*Aeronautical Facilities of the National Research Council*"
J. H. Parkin

2 DECEMBER
Social Night

MEMBERS

NEWS

J. L. Orr, F.C.A.I., Chairman of the Ottawa Branch, has been transferred from the Department of Defence Production to the post of Director of Engineering, Defence Research Board.

L. H. Kottmeier, A.F.C.A.I., of the Aircraft Division, Canadian Car & Foundry, has been appointed Vice-President in in charge of Sales.

P. J. Armitage, M.C.A.I., of Avro Aircraft Ltd. has been awarded an Avro scholarship to the Collge of Aeronautics, Cranfield. He will be in England for two years.

A. G. Duguid, M.C.A.I., General Sales Manager of Field Aviation has joined the Board of Directors of the Company.

H. A. Ross, M.C.A.I., recently sold his controlling interest in Ross-Aero Ltd. to John A. Timmins & Associates. Formerly Mr. Ross was President of the company, which he founded.

R. G. Halford, Associate and **V. Koby, Associate,** editors of Aircraft and Canadian Aviation respectively, have won the first and second prizes in the Trade and Technical Publications category of the Canadian Aviation Writing Awards.

MISSING PERSONS

R. S. Bradshaw M.C.A.I. formerly of Canadair Ltd. has changed his address without notifying the Institute and the Secretary is unable to get in touch with him. The Montreal Branch reports that he has returned to England, leaving no forwarding address. The Secretary would be grateful for any information on Mr. Bradshaw's present whereabouts.

SUSTAINING MEMBERS

NEW SUSTAINING MEMBER

THE following Company has joined the Institute as a Sustaining Member:

Standard Aero Engine Ltd.

NEWS

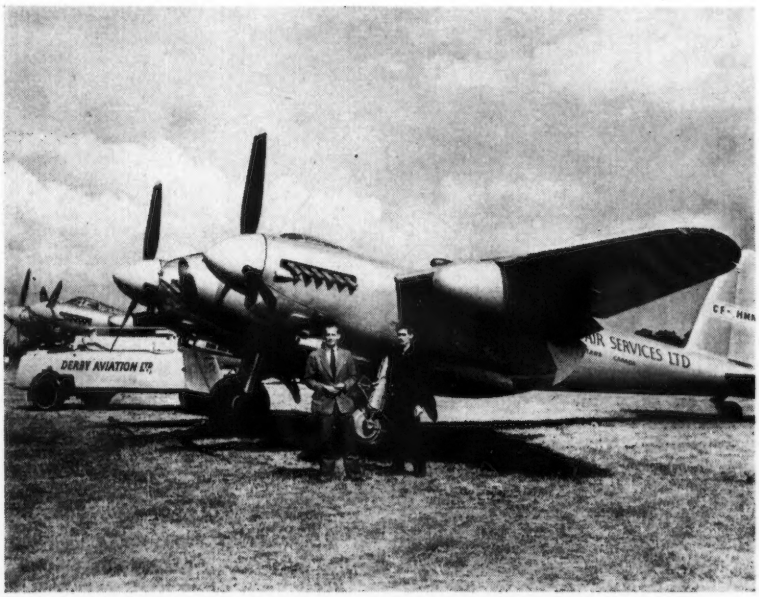
Canadian Aviation Electronics Ltd. Newsletter for September refers to adoption of the C.A.E. Airscint 1008 by Globe Airview Ltd. Globe Airview is an air survey company recently formed by Mr. Jean-Marie Cossette of St. Anne-de-la-Parade, Quebec. The Newsletter mentions an incident which contributed to the selection of the Airscint by Mr. Cossette. Crossing over Cartierville Airport at 2000 feet and calibrating his instrument, Mr. Cossette noticed the needle jump. On investigating he noted that he was flying in direct line with his parked car, in which he had left a radioactive sample!

Jarry Hydraulics announces two staff appointments. Mr. Peter Bray has joined the Company as Senior Designer responsible for servo-valve designs and Mr. Frank Ritchie has been appointed Test Engineer in charge of the Environmental Testing Laboratory.

Minneapolis-Honeywell Regulator Company Ltd. announces the development of a new instrument for laboratory and production testing, known as the Magnetik Null Indicator 2HG-1. This instrument performs both d-c null detection and linear deflection measurement. Chief features are its extremely low noise level—less than 2 microvolts—and its high stability, a zero drift of less than one division per hour. The low noise level means that interference by either 60-cycle or 120-cycle ripples (caused by motor, lamp or other noise sources) is virtually eliminated.

Housed in a compact case (7"x8"x12") the new instrument weighs only 16 pounds. In contrast to conventional galvanometers and other type null indicators, input terminals of the new unit are completely isolated from the chassis and the circuit ground of the instrument. This adds versatility. The linearity of the new instrument—plus or minus five per cent—provides accurate production testing of precision resistors, potentiometers, capacitors and other electrical components where the deviation from zero must be measured.

The unique features of the new instrument stem from incorporating the engineering design concepts of the firm's second harmonic magnetic converter. In addition to the above features, this design calls for the use of only one vacuum tube and requires no moving parts except the meter itself. The resulting simplicity of the circuitry assures reliability and minimizes maintenance. Power requirements for the new instrument are 115 volts, 60 cycle, 0.2 ampere.



Spartan Air Services' Mosquito

Aeroquip (Canada) Ltd. has announced the issue of a new Catalog of hose lines and couplings. Copies can be obtained from the company.

Spartan Air Services Ltd. are replacing their fleet of P.38 aircraft used for long-range high-altitude photographic survey with 10 Mosquito aircraft from Great Britain. A photograph of two of these aircraft being prepared for ferry flight by Derby Aviation Ltd., in England appears above.

Rolls-Royce of Canada Ltd. have given us a few particulars of the new R.B. 109 propeller turbine engine which has been developed by the English company. These are of some interest and are summarized below.

Rolls-Royce began the design of the R.B. 109 in 1953 using the mechanical and aerodynamic experience gained from current gas turbine engines. The design stage was followed by extensive rig testing of individual assemblies before a complete engine was built. Since then three experimental engines have been completed and are now on test, the first of these having made its initial run in the Spring of 1955. Testing is proceeding rapidly and further engines are under construction for development purposes.

The first flight of the R.B. 109 is planned for early in 1956 in a Lincoln flying test bed which is being adapted for this purpose. Roll-Royce, however, regard scheduled operational flying as an essential part of the development of an engine for airline service. This policy originated when four Dart engines were installed in two Dakota aircraft and completed 4,000 hours flying on scheduled operation, from which much valuable experience was obtained. As with the Dart, the intention is to gain similar

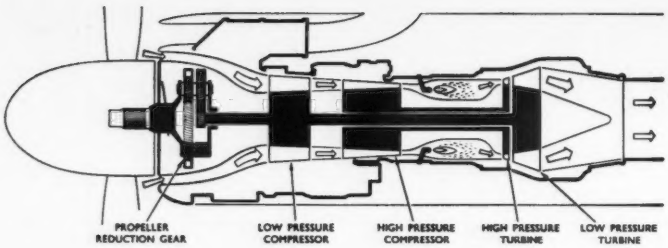


Figure 1
Diagramatic lay-out of the R.B. 109 engine

experience with the R.B. 109 by installing engines in Ambassador aircraft which will be put into scheduled service, possibly as freighters.

The R. B. 109 specific weight of 0.42 lb./tehp is 37% less than the Dart specific weight, yet at representative cruise conditions the R.B. 109 will start its service life giving 2.8 times the cruise power of the Dart when it first went into airline service with a 40% less specific fuel consumption.

For good economy at cruising conditions a high pressure ratio is required; the engine has therefore been designed around 12 to 1 pressure ratio, two-shaft, axial-flow compressor.

The arrangement of the engine as shown in Figure 1 is such that the high pressure compressor is driven by its own turbine and the low pressure compressor and the propeller are driven by a separate turbine, the shaft of which runs inside the high pressure shaft. The propeller is coupled to the low-pressure shaft through a compound epicyclic reduction gear, the internal mounting of which has been specifically designed to damp out vibration and thus improve engine reliability and also passenger comfort; these aspects have also been taken into consideration in the design of the engine mounting. In addition, considerable flight testing has been done to determine the relative importance of the various factors of the propeller turbine plant which affect noise. The results of these experiments have been applied to the design of the R.B. 109 engine to achieve maximum passenger and crew comfort.

The engine is controlled by a single throttle lever interconnected with the propeller controller. This, together with an automatic temperature control, maintains the correction relationship between power and propeller speed for take-off from aerodromes at differents altitudes and temperatures and also ensures maximum economy with changing air temperature and forward speed.

It is essential for a propeller turbine engine in a transport aircraft to maintain high propeller speed with minimum power under approach conditions to ensure maximum thrust reponse in the event of the necessity for an emergency acceleration. Provision has been made in the design of the R.B. 109 to meet this requirement. Provision has also been made for reverse pitch on the propellers to provide the braking which is now a standard feature of transport aircraft.

The de-icing system on the Dart engine has proved very satisfactory and the de-icing of the propeller, spinner and the air intake leading edge of the R.B. 109 is based on experience gained using the Dart system. Provision has also been made for anti-icing of the blades of the compressor based on comprehensive icing tests on axial-flow jet engines.

Leading particulars of the engine are as follows:–

Take-off
Power–4,020 shp,
1,175 lb thrust
Total equivalent power–4,470 tehp
Representative Cruising
25,000 ft, 425 mph
Power–2,270 shp,
150 lb thrust
Total equivalent power–2,470 tehp
Specific fuel consumption
0.414 lb/hr/tehp
Weight
Net dry weight–1,880 lb
Specific weight–0.42 lb/tehp
Dimensions
Length to cone fitting line–97.15 in
Height–40.5 in
Width–37.4 in
Propeller Reduction Gear
Ratio–0.062 to 1

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CANADIAN AERONAUTICAL INSTITUTE

MEMBERSHIP REQUIREMENTS

Individual membership of the Institute is divided into seven grades requiring qualifications which are defined in Article 7 of the By-laws. These qualifications are summarised in the following table.

Grade	Qualifications	Annual Dues	*Special Annual Dues
Student	Undergoing a course of study at an approved school of engineering or technology	$1.00	No Dues
Technician	Engaged in technical work in aviation	$3.00	No Dues
Technical Member	Engaged in scientific, engineering, research, manufacture or operation, in aeronautics or related fields, for 4 years or graduated from an approved school of engineering or science	$5.00	$2.00
Member	Engaged in aviation for 8 years and acquired a recognized standing	$6.00	$2.00
Associate	Engaged in aviation though not qualified for technical grades	$6.00	$2.00
Associate Fellow	Engaged in aeronautical science or engineering for 10 years and been in responsible charge or made outstanding contribution	$7.00	$3.00
Fellow	Been an Associate Fellow for 1 year and attained distinction in aeronautics	$8.00	$3.00

APPLICATIONS

Application for membership must be made on the approved form, which can be obtained from the Secretary, and which must be returned to the Secretary on completion. The applicant does not apply for membership in any specific grade, but each application is carefully considered by an Admissions Committee, who submit their recommendations in this regard to the Council. The Council is the deciding body. On admission the applicant is informed of his grading and the appropriate entrance fee and dues.

ENTRANCE FEES

The Entrance Fee is $5.00. Members in good standing in the R.Ae.S., I.A.S., I.A.T. or O.A.S., on the 1st of January 1954, who were resident in Canada at that time, are admitted without payment of entrance fee. Students and Technicians are also exempt from entrance fee but must pay a transfer fee, which is in effect a deferred entrance fee, when they transfer later on to one of the senior grades.

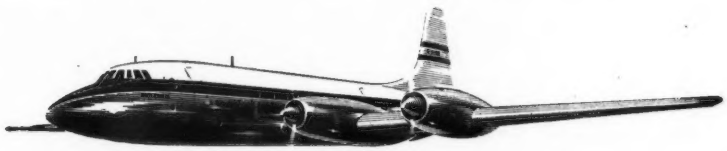
*SPECIAL ANNUAL DUES

Members of the R.Ae.S., I.A.S. and E.I.C., who are normally resident in Canada, enjoy a reduced rate of annual dues by virtue of the financial assistance which these bodies render to the Institute. This reduced rate is shown in the right-hand column of the above table.

SUBSCRIPTION TO C.A.I. PUBLICATION

In addition to the annual dues, all members are required to subscribe to the publication of the Institute, at a rate set by the Council but not exceeding $3.00 per year.

WORK CAPACITY



THE PRIME REQUIREMENT in developing new types of transport aircraft is to provide greater work capacity at lower cost per ton-mile. The formula for this increased earning power is the carrying of larger payloads at high speeds over longer non-stop distances, and flying as many hours out of the 24 as possible. Speed is, perhaps, the element that attracts most attention in all forms of transport, and speed is, of course, a function of power. Turbo-prop engines being built in Britain develop horsepowers considerably more than can be obtained from the piston engines which power all large, long-haul airliners at present in use.

Modern intercontinental airliners with their spares cost about a million pounds each, or roughly twice the price of the last generation of airliners. Their capital cost is usually depreciated over about six years, although their useful life is at least twice and nearer three times this period. The higher annual depreciation costs incurred would increase rather than lower the present operating cost unless the aircraft were capable of greatly increased work capacity. Each of the turboprop Britannias that Bristol is building can offer a yearly work capacity of about 11.5 million ton-miles—assuming each does 3,000 hours' flying a year at an average net speed (take-off to touch down) of 320 mph and carries 12 tons on each flight. In terms of passenger carriage—the measure being 10 passengers to the ton—this is equivalent to 115-million passenger-miles. In 1953 Pan American Airways made available 3,200-million passenger-miles, which corresponds to the potential annual output of 27 Britannias, compared with that airline's fleet of 105 main line aircraft in service last year. In practice, of course, paper plans and estimates do not work out so ideally as this, and a greater margin of fleet capacity is required. But the arithmetic serves to show how the advanced capabilities of these new aircraft will enable lower costs to shippers and the travelling public to be achieved.

This enhanced work capacity, therefore, is the produce of three factors: more speed due to greater power, longer range due to fuel economy combined with speed, and many more seats. To offer one of these without the other two is not enough. For instance, an annual average speed of 400 mph allied to a capacity of 5 tons, makes possible at the same 3,000 hours' yearly utilisation, a work capacity of only 6-million ton-miles per aircraft by contrast with the Britannia's 320 mph, 12-ton capacity and 11.5 million ton-miles a year. And if the range of new aircraft is limited because of high fuel consumption, the annual average speed is reduced by the need for more fuelling stops—to say nothing of the higher fuel bills. Moreover, as payload is always subject to the weight of fuel that must be carried for a given distance, very high speeds at high consumptions can be less rewarding than somewhat lower speed combined with more miles per gallon.

World competition for long range, heavy airliners has been taking the form of marginal advances in the designs of four or five manufacturers. Every few years range, payload and speed figures of the individual design have been inched higher. The Britannia has been evolved not only to provide all-round gains in these respects over existing piston-engined types, but to start life with a basis for continued improvement during the next 10 to 15 years as a normal process of development. The broadening new science of harnessing gas turbines to high-speed propellers offers powers, air-speeds and fuel consumptions that will steadily push the piston-engine farther into the background.

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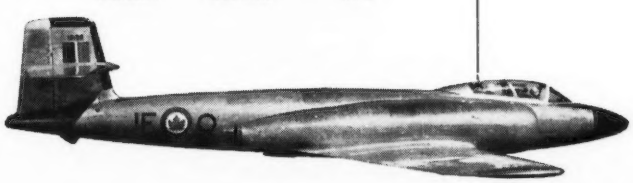

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NATIONAL AERONAUTICAL ESTABLISHMENT



The Montreal Road Laboratories of the National Research Council, Ottawa. Members attending the I.A.S./C.A.I. International Meeting visited this Establishment on the 4th November 1955. (See Page 232).

EDITORIAL

TEAM-WORK

First, we of the Vancouver Branch take this opportunity to send greetings to the other Branches and to the Executive of the C.A.I. The "we" in the preceding sentence is not the usual editorial "we" but represents the Executive and Members of our Branch who form a team of persons interested in learning more about their particular part of aviation, – and about the specialties of all the other members of this broad field of aeronautics.

That leads into the theme of this little discourse, the importance of team-work in aeronautics today, and the immense breadth of the object of the Institute – the advancement of the art, science and engineering relating to aeronautics. Team-work has been a most necessary part of aviation since its earliest days. It is perhaps symbolic that credit for the first powered flight goes to two brothers, and the story of Canada's first flight is an even better example of team-work.

Today, even our specialized fields have become so complex that in most of them we must work together if we are to accomplish great things. The sudden flashes of genius still occur, but more often the major steps forward are due to the combined contributions of a number of people. Scientific research and development, the engineering, manufacture and operation of aircraft all depend on good team-work in each section.

The complexities of modern aviation are such that good team-work is also essential between each section of an enterprise and between various companies interested in the success of a particular aircraft. It is no longer sufficient to plan the design of a new aircraft and then feel that success has been achieved if that aircraft can fly. Each of you will have an example in your own organization, but I might describe one from the point of view of the airline industry. Before a new transport aircraft can be produced, there must be the closest consultation between the various sections of the manufacturer to work out possible designs. There must be careful team-work between the manufacturer and the purchasing airline to guarantee that the characteristics of the aeroplane are well suited to the requirements of the airline along technical, operating, maintenance, and passenger carrying lines. In turn, there must be most careful work in assessing the wishes of the travelling public, the sales appeal of the various features contemplated and the aircraft utilization which can be obtained from the traffic density on particular routes. All these and many more features must be carefully studied and communicated through various sections of various companies back to the basic designer. If excellent team-work has conveyed the proper information the result is likely to be an advance of aircraft design most highly successful to the manufacturer, airline operator and travelling public. If this team-work has not been carried out, a beautiful aircraft may die on the design tables.

The C.A.I. has a very important part to play in the development of team-work in all aspects of aeronautics. In it the specialists can exchange information to increase their detailed knowledge of their specialty. We hope that membership of the C.A.I. will grow to include generous representation from all groups in any way concerned with aeronautics because to do our own job properly we must learn something more of each other's line in aviation and through that knowledge build up our team-work abilities.

Finally, the C.A.I. in its relations with the R.Ae.S. and the I.A.S. gives us an opportunity to exchange information with our colleagues in the United Kingdom and the United States and assists the team-work essential between the aviation interests of our three countries.

H. D. Cameron,
Chairman, Vancouver Branch

BUCKINGHAM PALACE.

From : Lieut.-General Sir Frederick A. M. Browning, K.C.V.O., K.B.E., C.B., D.S.O. 25th October, 1955.

Dear Richmond

I am desired by The Duke of Edinburgh to acknowledge your letter of 7th October, in which you express the appreciation of the Canadian Aeronautical Institute on His Royal Highness becoming Patron.

His Royal Highness has asked me to thank you for the kind sentiments you have expressed in the letter, and to assure you that as far as he is able he will find every opportunity of taking an interest in the doings of the Institute, and he has asked me to make a note of a possible visit next time His Royal Highness visits Canada.

Perhaps in the meantime you would let me know when anything of special interest occurs which should be brought to His Royal Highness' notice.

Yours sincerely
Fred Browning

R. D. Richmond, Esq.,
The Canadian Aeronautical Institute,
104A O'Connor Building,
304 Laurier Avenue W.,
Ottawa 4, Canada.

MATERIALS AND FABRICATION TECHNIQUES FOR STRUCTURAL HEAT-RESISTANT PLASTIC SANDWICHES†

by **Norman E. Wahl***

Cornell Aeronautical Laboratory

AIRCRAFT design engineers have considered many methods to overcome the inherent shortcomings of light weight materials. Perhaps one of the most intriguing ideas has been the use of sandwiches.

The combination of various low strength materials into structural sandwiches is not new, but the expansion of this principle into aircraft use is fairly recent.

The purpose of presenting this paper is to review some of the work carried out at Cornell Aeronautical Laboratory on non-metallic materials and to present the fabrication techniques used in the production of a structural sandwich wing using the materials developed.

CORE MATERIALS

For the last several years, a substantial amount of our research work on plastics has centered on the investigation and development of materials and techniques for the construction of sandwich radomes for high speed aircraft and missiles. These radomes of necessity, were non-metallic in nature with skins of glass reinforced plastics and cores of balsa or glass fabric honeycomb.

Due to the compound curvature of the radomes, the balsa or honeycomb core was extremely difficult to shape, and the fabrication processes were time consuming. These core materials also had a limited resistance to heat.

The early work at Cornell Aeronautical Laboratory therefore involved the development of a new core material under the sponsorship of Wright Air Development Center.

The target objective of the program was the development of materials, formulations, and processes for a foamed-in-place core material having the following principal characteristics.

1. Low density:—weight, in range 8-10 lb./cu ft.
2. Good mechanical properties:—satisfactory strength at room and at elevated temperatures, i.e., ultimate tensile and compressive strengths of 300 psi, and shear modulus of 10,000 psi at room temperature. At 500°F., 50% of the strength at room temperature after soaking for one-half hour at 500°F.
3. Good electrical properties:—dielectric constant of 1.25 and loss tangent of .004 at frequencies ranging from 60 cycles up to 30,000 megacycles.
4. Adhesion:—the adhesion at the interface between the core and the glass reinforced laminate skin with shear strengths in excess of 100 psi.
5. Uniform structure:—the foam cells shall be small, homogeneous, with no voids over ⅛" in diameter. No large cracks shall appear after heating at 500°F. for one-half hour.
6. Ease of handling:—the core material shall be such that it is easily processed, requiring no specially trained personnel. The core material must lend itself to use in sandwich designs involving compound curved shapes. The sandwich skins, between which the core material is to be expanded, will range from approximately .010 to .060" in thickness. The total thickness of the sandwich ranges from ¼" to ¾".

With no restriction on the use or selection of raw materials, processes, and techniques, it would appear on first analysis that no great difficulty should be experienced in developing a satisfactory heat resistant foamed-in-place core material. The paradoxical nature of the program, however, soon becomes apparent when one starts to make such foams. To make a good, uniform core material is one thing; to make good, high strength, low density, heat resistant, foamed-in-place material is definitely another.

FOAMING PROBLEMS

The first six months of the program were spent in the evaluation of commercially available resins for foams,

†Paper read at the I.A.S./C.A.I. International Meeting in Ottawa, on the 4th November 1955.

*Head, Plastics Section, Materials Department.

foaming agents and methods of foaming. In this preliminary survey it was found that none of the commercial resins or foaming agents gave a core material that even approached the target objective. It was also established that the foaming technique developed by Goodyear Research Laboratory, under a previous Wright Air Development Center contract, offered the best method for obtaining a foamed-in-place core material with the uniformity desired for radome sandwich structures. This foaming process involves the reaction of alkyd resins with isocyanates to give a polyurethane and carbon dioxide. The carbon dioxide, which is a product of the condensation, acts as the foaming agent.

A number of isocyanates were studied, and in general, 2,4 m-tolylene diisocyanate gave the most satisfactory results. Using this isocyanate, and also testing with other foaming agents, commercial resins were investigated in an effort to develop a high temperature, foamed-in-place core material. The commercial resins invariably failed for one or more reasons. The most common defect was the inability to be adapted to any foaming technique and this resulted in very poor quality foams, or in some instances, a total collapse of the foamed product.

Many experimental resins were formulated in an effort to devise a good heat-resistant foaming alkyd material. Among the intermediates that were investigated were phthalic and chlorinated phthalic anhydrides, and many other polybasic acids. The polyfunctional alcohols that were studied included glycerol, ethylene, diethylene and propylene glycols, mannitol and pentaerythritol.

For the purpose of screening the resins and foams developed, the foams were tested in compression at temperatures arbitrarily selected as 75°F., 300°F., 375°F., and 400°F. after soaking for one-half hour at those temperatures.

LAMINAC 4231

A polyurethane foam approaching the target objective of this program has been prepared from one of the unsaturated alkyd-triallylcyanurate copolymeric resins developed, using tolylene diisocyanate for a foaming agent. Such foams have retained a large percentage of their strength when tested at 400°F., after soaking for one-half hour at those temperatures. The best of these resins, No. 31, has been produced by American Cyanamid Company on a pilot plant scale. It is being offered for sale as Laminac 4231.

Foams ranging from 3 to 20 pounds per cubic foot can be made from Laminac 4231. Figure 1 shows how the compressive strength at room temperature varies with the density.

The table below outlines the typical compressive strength obtained with resin No. 31 at various temperatures.

COMPRESSIVE STRENGTH
(psi)

Resin No.	Density (lb/ft³)	75°F	300°F	375°F	400°F	% Loss		
						300°F	375°F	400°F
31	12.5	295	280	270	220	4.4	7.5	26.2
31	11.0	205	200	175	150	2.5	15.0	26.5
31	9.7	162	134	122	110	17.5	24.7	32.0

Figure 2 shows the flatwise compressive strength at various temperatures, of a sandwich with 1/32" glass reinforced skins.

Figure 3 shows the typical flexural strength of a similar sandwich at 75° and 400°F.

Figure 4 shows the average shear strength of the same sandwich at 75° and 400°F.

A considerable amount of development work had to be carried out in perfecting the foaming technique. Such problems as the proper catalyst and cure, methods of mixing the resin and foaming agent, all had to be worked out.

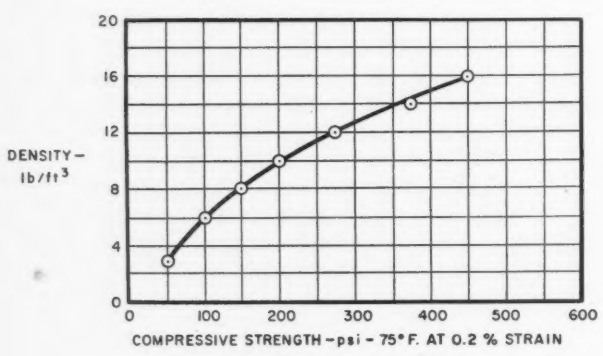


Figure 1.
Average compressive strength vs density of polyurathane foam from Laminac 4231

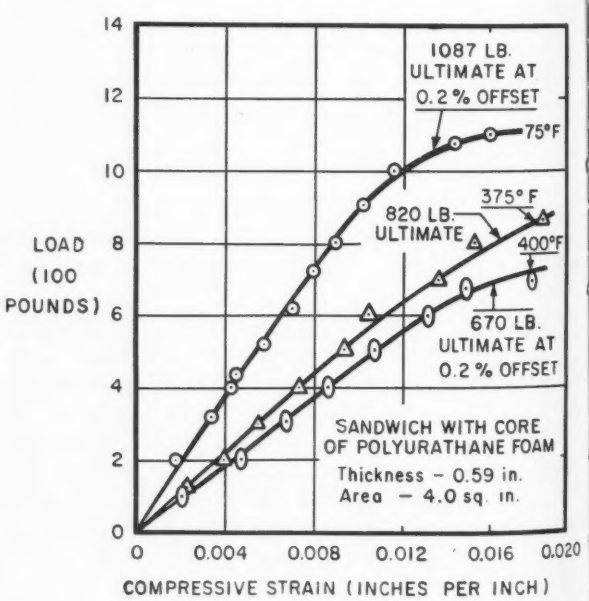


Figure 2.
Average flatwise compression — 10-lb. density foam

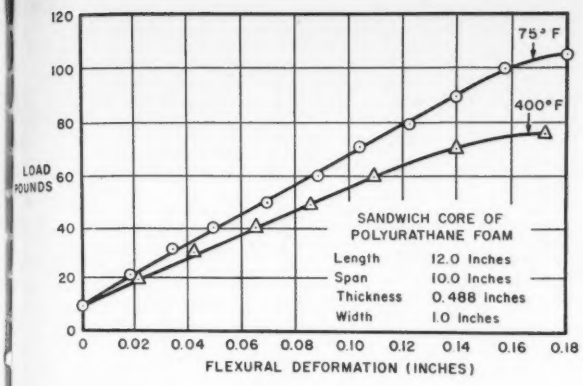


Figure 3.
10 lb. density foam
Average flexual or bending strength

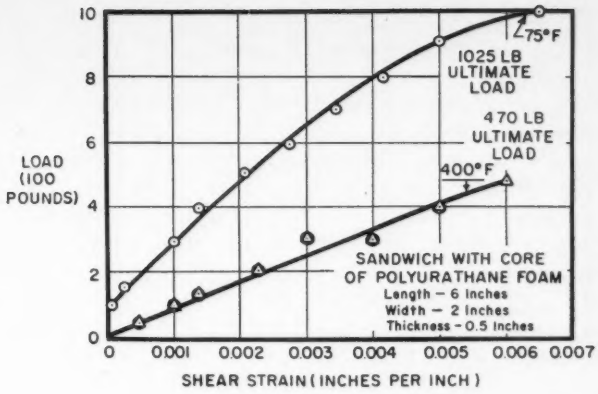


Figure 4.
Average shear strength—psi
(11 lb. per cubic ft. density)

FOAMING PROCESS

The complete foaming process developed is as follows:

Step 1. A weighed amount of resin is poured into mixer.

Step 2. For every 100 parts of resin by weight, 85 parts by weight of tolylene diisocyanate is added slowly to the resin. When the tolylene diisocyanate, which has a viscosity in the same range as water, is added all at once to the alkyd resin, it floats on top of the resin and there are two distinct phases. When the mixer is started, the tolylene diisocyanate splashes out; it is therefore necessary to add this material in about four or five portions at three to four minute intervals. The mixing of the tolylene diisocyanate and the alkyd resin into a homogeneous blend takes 20-25 minutes at 75°F.

Step 3. The reaction between the foaming agent and the alkyd resin is very exothermic. It is necessary to keep the batch at a temperature of 75° to 85° at all times by the addition of crushed dry ice. If the temperature is allowed to reach 95°F., the reaction will proceed so rapidly that the entire foaming reaction will be completed in a few minutes without any control.

Step 4. After the tolylene diisocyanate has been completely blended into the Laminac 4231 in 25 minutes, 2-3% by weight of di-tert-butyl peroxide catalyst, based upon the resin, is added to the mixture.

Step 5. As the reaction proceeds, the viscosity increases. After 35 minutes of total mixing time has elapsed, the viscosity of the mixture is taken at three to five minute intervals until a viscosity of approximately 1,500 poises at 80° to 85°F. is reached. This viscosity is usually reached after 45 to 55 minutes of total mixing time. At this time 8 to 10% by weight (based upon the resin) of Aerosol-Acetone solution is added. (This solution contains 10% of Aerosol OT in 90% of dry acetone).

Step 6. Mixing of the Aerosol-Acetone into the foam is continued until a reduced viscosity of 300-500 poises is reached. The foam is then poured into the mold. The mold is then closed and the foam cured for one hour at 150° to 160°F., 2 hours at 300°F. and 2 hours at 375°F. The mold is then cooled to room temperature.

The results obtained in this program represent an advance in the use of structural, high strength, heat resistant, core material that can be foamed in place.[1]

OTHER PROJECTS

As a logical corollary to the work on heat resistant sandwiches, we have just undertaken a developmental study of heat resistant laminates for Wright Air Development Center under Contract No. AF 33(616)-2515.

In this work our objective is to develop improved, heat resistant polyester-triallylcyanurate copolymer glass reinforced laminates that will not crack or craze upon postcuring or exposure to 500°F. for extended periods.

Since this program is relatively new, we have only obtained preliminary data. Figure 5 indicates how the flexural strength and modulus of elasticity is reduced as a glass reinforced laminate is exposed to elevated temperatures for ½, 200 and 1,000 hours.

Another investigation at the Laboratory was aimed

Time of Exposure in Hours	Exposed at 300°F. Flex.	Tested $E\text{-}10^6$	Exposed at 400°F. Flex.	Tested $E\text{-}10^6$	Exposed at 500°F. Flex.	Tested $E\text{-}10^6$
0.5	45,000	2.8	42,700	2.7	32,000	2.6
200	46,200	2.7	40,000	2.6	18,000	1.7
1000	40,000	2.8	38,600	2.4	5,000	1.0

Figure 5.
Ultimate flexual strength and modulus of elasticity of glass reinforced triallylcyanurate laminates after exposure to elevated temperatures.

at exploring the feasibility of designing and fabricating a light-weight, high-strength, missile wing of sandwich construction. The wing has a glass-reinforced plastic skin and uses the low-density, high-strength core material developed under the project described above. An important part of the program is concerned with the possible savings in costs and production time that such construction will afford. The following are the main phases of the work program:

Investigation of wing design and structure
Design of wing
Mold design and construction
Fabrication of prototype wing
Fabrication of two wing sections
Final report, including drawings, fabrication technique,
and comparisons with conventional missile wing.

To date the first four phases of the above program have been completed and static testing of the second prototype wing is scheduled to get under way very shortly.[2]

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Lift and Lift Distribution of Wings in Combination with Slender Bodies of Revolution

(See Pages 205 to 217)

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LIFT AND LIFT DISTRIBUTION OF WINGS IN COMBINATION WITH SLENDER BODIES OF REVOLUTION†

by **Dr. H. J. Luckert***

Canadair Limited

SUMMARY

Various methods are available for the purpose of calculating the lift distribution on a wing-body combination. The methods of Lennertz and Multhopp treat the case of an unswept wing in combination with a slender body in subsonic flow. They are based on the lifting line theory and only applicable to high aspect ratios and small ratios of body width to wing span. The Spreiter theory deals with delta wings of low aspect ratio, in mid-wing combination with slender bodies of revolution. Low and Stone's method, based on Spreiter's work and derived for rectangular wings in mid-wing combination with slender bodies of revolution, yields, by approximation, the total lift coefficient of the configuration, but no lift distribution.

The present work attempts to cover the whole range of aspect ratios and ratios of body width to wing span, by a practical and convenient method. It is seen to give the same results as the other methods in their respective limited ranges of validity.

In a special case where systematic wind tunnel tests were available for a wing-fuselage combination, without and with full and partial span flaps of various types, a comparison between calculation and test has been made and good agreement is shown.

INTRODUCTION

AFTER aerodynamic theory had been developed to the extent that it was possible to predict the aerodynamic characteristics and lift distribution along the span of an isolated wing with satisfactory accuracy, the question of the effect of a fuselage in combination with the wing became of increasing interest. In the early days, the body influence was not taken into account at all for design and stress calculations, but it became evident, with the design of larger and faster aircraft, that the body effect could not be neglected. Wind tunnel tests showed that the total forces on a wing-body combination may differ considerably from those on the wing alone. The simplest method of accounting for this effect was to charge only the body with the resulting differences, that is, to apply them to the body region alone. This procedure yields a result which is usually on the safe side from the point of view of stress calculations. The situation is illustrated by Figure 1 which shows the lift distribution (i) of the wing alone, (ii) of the wing with the body effect applied only to the fuselage region, and (iii) the actual distribution.

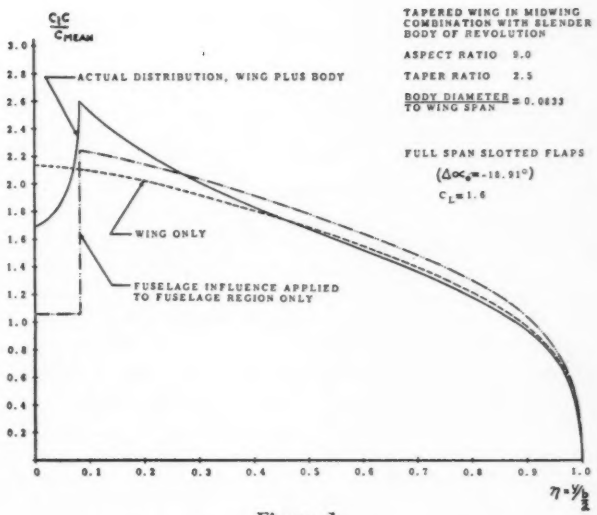


Figure 1.
Lift distribution on wing-body combination.

The second case gives higher bending moments than the other two and may, for some configurations, lead to excessively conservative results which would increase the structural weight unnecessarily.

Another question which arises in this connection is the body effect in the case of a wing with flaps. As an example, Figure 2 shows a wing-body combination on which systematic tests were made.[1] The model consists of a slender body which has a circular cross-section in the neighbourhood of the wing, and a trapezoidal wing of taper ratio 2.5:1 and aspect ratio 9.0 with a dihedral of 3°. The 25% chord line is unswept; the profile sections are NACA 65-210. The wing was equipped with full span flaps as well as 60% flaps, and the investigation was made for split flaps, single slotted flaps, and double slotted flaps. For each type of flap, force tests were carried out for the configurations wing alone ("Fuselage off") and wing plus body ("Fuselage on"). In the "fuselage-off" case, the flaps extended to the plane of symmetry. For the partial-span flaps, the configuration with flap cutouts in the body region was also measured ("Flap cutouts"). Consequently, these tests are very

†Paper presented at the Annual General Meeting of the CAI, in Toronto, on the 20th May 1955.
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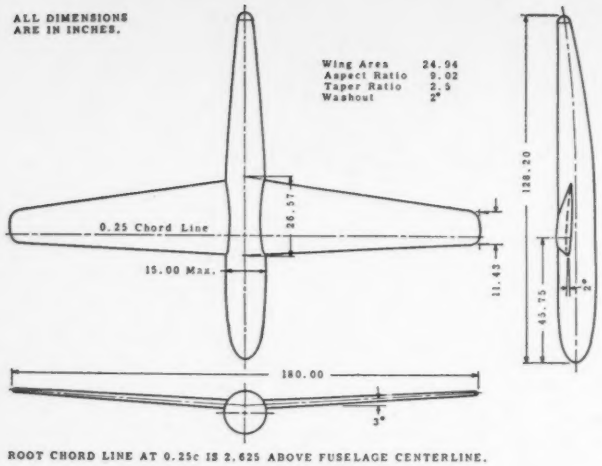


Figure 2.

Wing and fuselage for tests in Langley 19-foot pressure tunnel (NACA TN No. 1579).

informative, and especially interesting in the case of partial span flaps of different types. Figure 3 shows the test results for the single slotted flaps. The results reveal, for example, in the case of partial span flaps, that the configuration "fuselage on" yields higher C_L values, throughout the α region, than the configuration of wing alone with flaps and cutouts. This means that evidently some lift is "carried across" the fuselage. However, comparing the results for partial span flaps in the case of split flaps, slotted flaps, and double slotted flaps (Figure 4), it is seen that the various flaps do not behave in the same way, and the general conclusion may be drawn that only a little lift is carried across in the case of split flaps, approximately 30% in the case of single slotted flaps, and approximately 40% in the case of

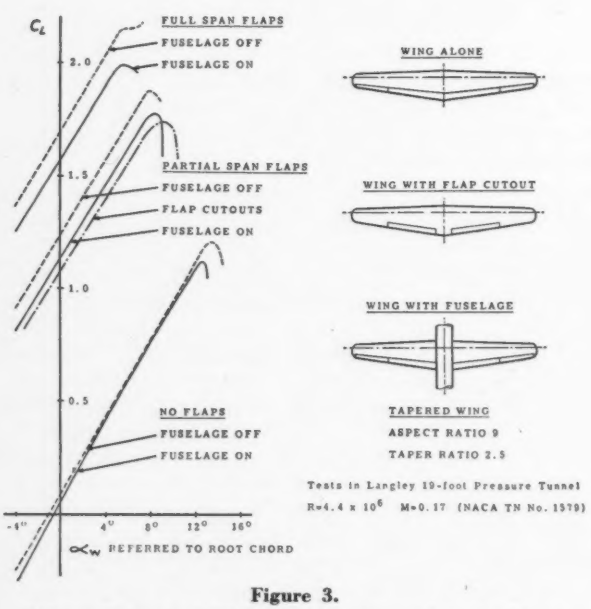


Figure 3.

Lift coefficients of NACA 65-210 wing with and without single-slotted flaps and fuselage.

double slotted flaps. It would be of interest to check whether a theoretical calculation would give the same effect and, consequently, explain the experimental results.

For these reasons it became important to investigate the wing-body problem more accurately. Since the design trend is evidently towards lower aspect ratios and larger fuselage diameters (for fuel storage, etc.) it is necessary that such configurations can be handled satisfactorily, in the calculation of lift distribution as well as of overall aerodynamic characteristics.

The earliest investigations were those of Lennertz[2] who calculated the lift distribution for a wing of high aspect ratio attached to an infinite circular cylinder, by using a horseshoe vortex for the wing and images of the trailing vortices in the circle. In 1941 Multhopp[3] developed a linear theory which is also based on the lifting line; he arrived at a simple method of calculation, using conformal transformation. As in lifting line theory,

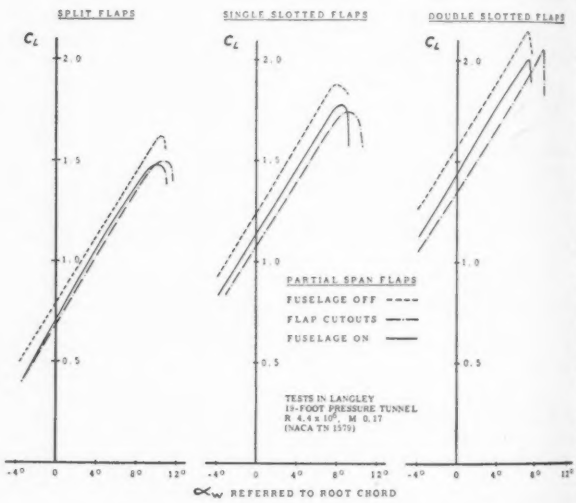


Figure 4.

Lift coefficients of NACA 65-210 wing with partial span flaps, (60%), with and without fuselage.

the method assumes that the wing is thin and unswept, and that it can be replaced by a vortex line. This requires the wing chord to be small compared to the span and the body diameter. It follows that the method is applicable only to large aspect ratios and to small ratios of body diameter to wing span.

Multhopp's method has been extended, by Weber, Kirby and Kettle,[4] to take account also of wing thickness, large chord-diameter ratios and sweep-back by simple devices.

Both the above methods, by Lennertz and Multhopp, are based on the lifting line theory and, therefore, cannot safely be applied to small aspect ratio airfoils as they occur in tail units or missiles with small fins, or in wing-body combinations with very large body-diameter-to-wing-span ratios. Recently, methods have been developed for these cases.

The Spreiter theory[5] deals with the case of delta wings of small aspect ratio in combination with slender

bodies of revolution such as conical bodies, semi-infinite cylindrical bodies, and bodies pointed at the nose but cylindrical at the wing root chord. This theory, which is linear, is valid for all ratios of body diameter to wing span, and applies to subsonic, transonic, and, under certain conditions, supersonic speeds. The paper by Lawrence[6] also takes account of the non-linear dependence of the aerodynamic characteristics of a wing on the angle of attack. Low and Stone[7] have presented a method, based on the Spreiter and Lawrence theories, for calculating the total lift for small-aspect-ratio wings, with slender cylindrical bodies of revolution pointed at the nose.

From a general point of view, Lawrence and Flax,[8] in their very comprehensive paper, treat the subject by giving a common basic formulation so that the significant assumptions made in developing each theory and the relationships between them, can be more clearly seen. Their monograph covers subsonic and supersonic flow, and some new developments are also included.

The object of the present paper is to study the above-mentioned methods with respect to their limitations and from the point of view of practical applications. Since each method only covers a certain limited range of aspect ratios and body diameter ratios, an attempt has been made to develop a simple method which can be applied over the whole range and which gives satisfactory results for practical purposes.

To restrict the scope of this paper, only the problem of an unswept wing in mid-wing combination with a slender body of revolution in subsonic flow is considered.

First, a general outline of the problem will be presented for the subsonic case, including the principal ideas on which the calculations described here are based. Then a short description of the theory due to Multhopp is given and of those due to Spreiter, and Low and Stone, showing their limits of validity. The present method is next explained, and it is shown that the suggested method tends to give the same results as the other methods in their respective range of applicability. Some special results are then discussed, and the final section contains the concluding remarks.

LIST OF SYMBOLS

a_0 two-dimensional lift slope

A aspect ratio

A_{exp} aspect ratio of exposed wing

A,B semi-axes of ellipse

b wing span

C_L lift coefficient referred to hypothetic basic wing
Subscripts: WB wing-body combination
W wing only
B body

C_L^* lift coefficient referred to exposed wing area
Subscripts: WB wing-body combination
W_{exp} exposed wing

C_{L_α} Lift curve slope, $\frac{dC_L}{d\alpha} = C_L{}_{(\alpha=1)}$
$C_{L_{\alpha_0}} = C_{L_\alpha}$ for $\sigma = 0$

C_L $C_L\,(\alpha_F = 0,\ \alpha_w = 1) = \frac{dC_L}{d\alpha_w}$,
$C_{L_{\epsilon_0}} = C_{L_\epsilon}$ for $\sigma = 0$

c_l local lift coefficient

c chord

c_{mean} geometric mean chord

d diameter of fuselage (circular cylinder)

$f(y)$ upwash function

G non-dimensional circulation

$L(k)$ L-function, $L\ (k) = \frac{\sqrt{1+k^2}-1}{k}$

L_W lift on wing

L_B induced lift on body

p wing-parameter function, $p = \frac{2b}{a_0 c}$

R radius of fuselage with circular cross-section

$\mathcal{R}$ real part of $\frac{d\bar{u}}{du}$

u complex variable, $u = z + iy$

$u\,(u)$ conformal transformation function

w_{n_F} upwash on wing due to fuselage, $= V_0 \alpha_F f(y)$

V_0 free-stream velocity

y co-ordinate in spanwise direction

z co-ordinate in direction perpendicular to fuselage and y-axes

$\mathcal{P}(G;p)$ symbol for

$$\frac{1}{2\pi}\int_{-1}^{+1}\frac{\frac{dG}{d\eta'}\,d\eta'}{\eta-\eta'} + p\times G$$

$\mathcal{L}(G;\lambda)$ symbol for

$$\frac{2}{2\pi}\int_{-1}^{+1}\frac{\frac{dG}{d\eta'}\,d\eta'}{\eta-\eta'} + \frac{\lambda}{2\pi}\int_{-1}^{+1}\frac{dG}{d\eta'}\,L[\lambda(\eta-\eta')]\,d\eta'$$

α angle of attack

α_F angle of attack of fuselage axis

α_w local angle of attack of profile zero lift line

$\Delta\alpha_0$ change of two-dimensional zero lift angle due to flap deflection

i_w wing incidence setting, angle between zero lift line of wing and fuselage axis

Γ circulation

λ local aspect ratio b/c

μ axis ratio of ellipse, $\mu = \frac{B}{A}$

σ ratio of body diameter to wing span

η non-dimensional co-ordinate, based on semi-span, $\frac{y}{b/2}$

η_F non-dimensional co-ordinate, based on body half-width $\frac{y}{d/2}$

ϕ velocity potential

Barred symbols: values in transformed plane.

GENERAL CONSIDERATIONS

It is known that for an isolated body the total lift force is zero in non-viscous flow, and that, approximately, the local lift is proportional to the angle of attack and the change of the cross-sectional area along the axis. This means that in the front part of the body there is a lift force, and near the tail where the cross-section decreases, a download. If the body has a cylindrical centre part, and this is usually the case in conventional configurations, the lift is zero in this region.

Now consider a wing-fuselage configuration. The flow about each part will be modified by the presence of the other part.

The influence of the fuselage on the wing is, in the first place, a change of the magnitude and the direction of flow at every station of the wing. Moreover the fuselage acts as a boundary and, therefore, no velocity components perpendicular to the body surface can exist. The boundary layer flow of the fuselage may also have an effect; however, this influence is only small for usual aerodynamically acceptable combinations and may be neglected for present purposes.

The flow around the body can be split into two components:

1) The perturbation flow parallel to the fuselage axis, and
2) The perturbation flow perpendicular to it.

The first component produces a slight increase in speed which decreases with increasing fineness ratio of the body; it becomes zero if the body is a cylinder of infinite length. The second component, perpendicular to the body axis, is an upwash, proportional to the angle of attack of the fuselage axis, and it changes the effective angle of attack at the wing. It can be shown that, comparing two bodies of different fineness ratio, the resulting effective angle of attack is nearly independent of the fineness ratio[3]. In consequence, for calculation purposes

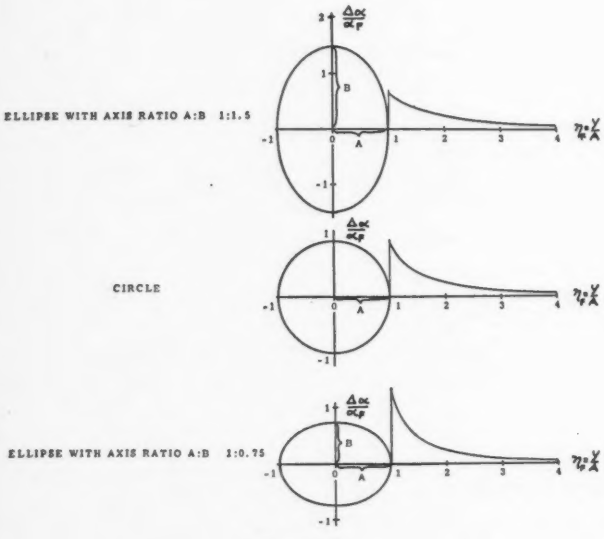


Figure 5.
Upwash produced by circular and elliptical cylinders of various axis ratio *A:B*.

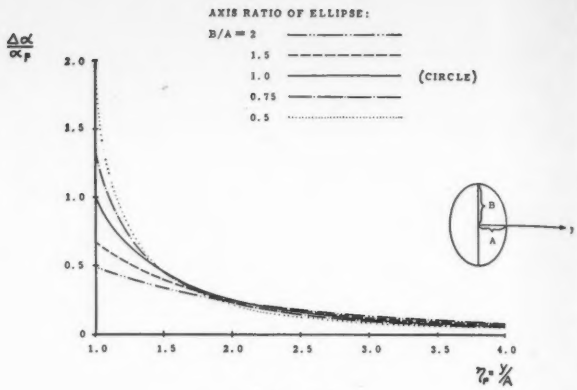


Figure 6.
Upwash produced by elliptical cylinders of various axis ratio *A:B*.

an infinitely long cylinder, having the same cross-section as the body in the wing region, can be assumed; this assumption has been justified by experiment. Now the calculation is considerably simplified: for an infinitely long cylinder no velocity changes but only changes in angle of attack must be considered. The upwash w_{nF} (proportional to $\alpha_F \times V_o$) on the wing can be determined from the two-dimensional flow around the cylinder. The additional angle of attack is given by $\frac{w_{nF}}{V_o} = \Delta\alpha$ which is proportional to α_F and depends only on the cross-section of the body and the position of the wing with respect to the fuselage. Figure 5 shows the angle distribution along the span, $f(y) = \frac{\Delta\alpha}{\alpha_F}$ for elliptic cylinders of various axis ratio in mid-wing configurations. For a circular cylinder, $f(y)$ becomes $\frac{1}{(y/R)^2}$ where R is the radius of the cylinder and y the distance from the centre. The figure shows that the upwash, which decreases rapidly with increasing distance from the centre, no longer depends on the cross-section at large distances. Only in the immediate neighbourhood of the body do great differences occur (Figure 6). The flow around other cross-sections has been calculated by Liess and Riegels[9] for various wing positions. The determination of the cross flow around any cross-section is a matter of conformal transformation, and for the present investigation the distribution $f(y) = \frac{\Delta\alpha}{\alpha_F}$ can be assumed to be known and given. Using the above assumptions the problem is now reduced to that of finding the load distribution on the combination with a given distribution of angle of attack along the wing span. The resulting load distribution must fulfil the requirement that the induced downwash field added to the free stream velocity has no velocity component normal to the surfaces of both the wing and the body.

A convenient way to attack this problem is to use Trefftz considerations, according to which the potential function of the perturbation flow far behind the wing is connected with the circulation, if the assumption is made that the wake follows the direction

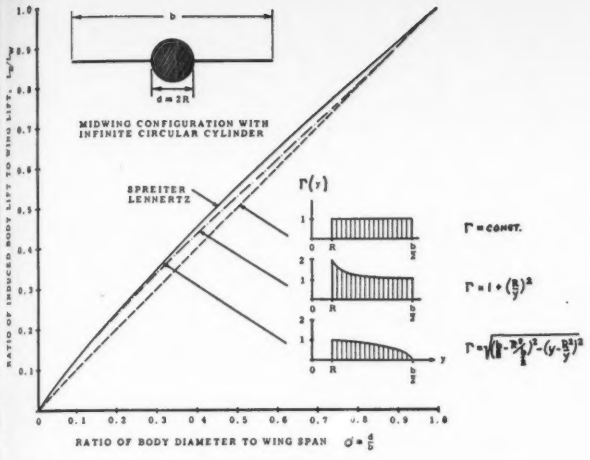


Figure 7.
Ratio of body lift to wing lift for various wing lift distributions.

of flow, and the rolling up of the vortex sheet is neglected. Far behind the wing, in the so-called Trefftz plane where the conditions are two-dimensional again, the section in a spanwise direction of wing plus body is the same as that in the actual plane. Moreover if ϕ is the value of the potential of the perturbation flow far behind the wing, and Γ the circulation at any point along the span, the following relation holds

$$\phi_{\text{upper side}} - \phi_{\text{lower side}} = \Gamma$$

It consequently remains to satisfy the boundary conditions in the Trefftz plane, provided that their relations with the boundary conditions on the body and wing are known.

For the lift in the body region the theory furnishes a simple result. It can be shown that the total lift on the body (and this is of more interest than the circumferential distribution) is related to the lift distribution over the attached wing by

$$L_B = \rho V_o \int_{\text{WING}} \Gamma(y) \times f(y)\, dy$$

where

V_o = free stream velocity
y = ordinate in spanwise direction
Γ = circulation along the wing span, and
$f(y)$ = the velocity distribution normal to the wing surface produced at the wing station y by a vertical transverse flow around the body of unit velocity; i.e. the upwash function explained above.

Moreover, as has been pointed out by Lawrence and Flax[8], the ratio of this induced body lift to the wing lift, L_B/L_W, is relatively insensitive to the details of the lift distribution on the wing for many practical cases. If, for example, the case of a mid-wing configuration with a circular cylinder is considered, Figure 7 illustrates the effect of various (and quite different) forms of lift distributions on the ratio L_B/L_W. It is seen that the resulting curves do not differ very much from each other.

Even the very rough approximation Γ = constant along the span, for which the ratio L_B/L_W turns out to be proportional to the ratio of the body diameter to the wing span, $\frac{d}{b} = \sigma$, yields values which are not much different from those obtained by Spreiter (pointed wings of low aspect ratio) and Lennertz (high aspect ratio wings). It follows that, for practical purposes, it is not critical whether or not the correct lift distribution over the wing is used in determining the body lift; therefore, the Spreiter-Lennertz curve, being the most realistic one, may be taken for practical calculations of the body lift.

If the wing lift has been determined, the total lift of the combination follows immediately from

$$L_{WB} = L_W + L_B = L_W\,(1 + \frac{L_B}{L_W}).$$

It thus remains to determine the wing lift, and in the following some methods for the calculation will be discussed.

THE MULTHOPP METHOD

In the foregoing section the main ideas of the calculation have been dealt with. Now a short outline of the Multhopp method will be given.

Multhopp makes the assumption, corresponding to the lifting line theory, that the angle of attack, induced by the trailing vortices, at the wing and body is equal to half its value at infinity, that is, in the Trefftz plane. In this way a relationship is given between the conditions on the wing and in the Trefftz plane. The boundary condition on the body can then easily be satisfied by applying a conformal transformation which maps the fuselage cross-section (in the U-plane, $u = z + iy$) into a vertical slit (in the $\overline{U}$-plane, $\overline{u} = \overline{z} + \overline{iy}$). Figure 8 shows the transformation for a mid-wing configuration and a fuselage of circular cross-section. The transformation can be explicity given if the cross-section of the fuselage is circular or elliptic; for other forms it can always be

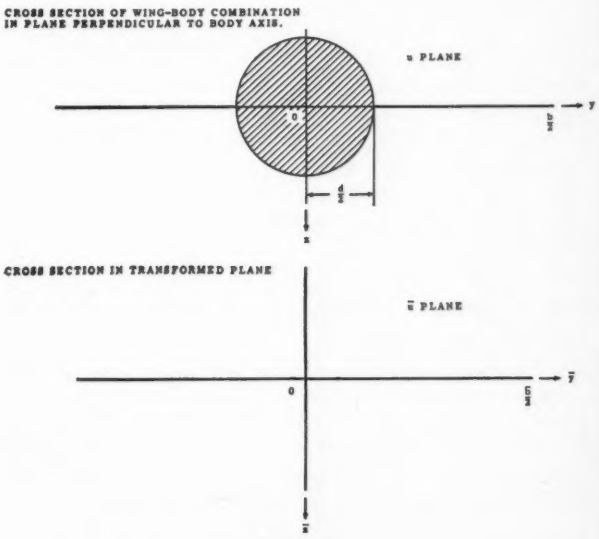


Figure 8.
Conformal mapping.

found by successive approximations. In the $\bar{U}$-plane, the contour of the fuselage automatically becomes a streamline for the vertical flow component. By conformal transformation the potential ϕ and hence the circulation Γ remain unchanged. However, the derivatives of ϕ in the $\bar{z}$-direction (giving the velocities in that direction) must be multiplied by a factor $\mathscr{R}$, which follows from and is determined by the function of transformation. Using all these relations, an equation is finally obtained for the non-dimensional circulation in the mapped plane[12]. This equation has the exact form of the equation for the circulation of a wing alone, whose chord is the chord of the original wing times the factor $\mathscr{R}$, and whose wing setting is the original divided by the factor $\mathscr{R}$. In symbols,

$$\mathscr{P}(\bar{G};\bar{p}) = \alpha_F + \frac{\alpha_W - \alpha_F}{\mathscr{R}},$$

where

$\bar{G}$ = non-dimensional circulation in the mapped plane,

$$\bar{G} = \frac{\Gamma}{\bar{b}V_o}$$

$\bar{b}$ = wing span in the mapped plane,

$$\bar{p} = \frac{2\bar{b}}{a_o c \mathscr{R}}$$

α_F = angle of attack of body axis

α_W = local angle of attack of wing,

and the symbol $\mathscr{P}$ stands for

$$\mathscr{P}(\bar{G};\bar{p}) = \frac{1}{2\pi}\int_{-1}^{+1} \frac{d\bar{G}}{d\bar{\eta}'}\frac{d\bar{\eta}'}{\bar{\eta}-\bar{\eta}'} + \bar{p}\times\bar{G}\,.$$

The relations between the original and the mapped plane are given by the transformation, and consequently, if the distribution in the transformed plane had been calculated, the distribution in the original plane is also given.

Using the relationships between the circulation and the potential, and assuming that the potential changes linearly along the vertical slit (which can be done for small distances, that is, small body diameters), the lift distribution in the body region can be determined. For circular and elliptic cross-sections the lift distribution turns out to be elliptical, and only the value at the centre need be calculated. This can easily be done. For details, reference must be made to Multhopp's paper[3], or Reference 12.

It is of interest to compare the computed body lift with the results by Spreiter and Lennertz discussed in the former section. According to the assumptions made in the Multhopp method it must be expected that the agreement is good for small body-diameter-to-wing-span ratios, and for high aspect ratios. This is indeed so, as can be seen from Figure 9. For a rectangular wing of aspect ratio 6, the values of C_{L_B}/C_{L_W} have been determined, with a two-dimensional lift curve slope $a_o = 5.73$. It is seen that the agreement is good for small values of σ, the differences becoming larger with increasing body diameter.

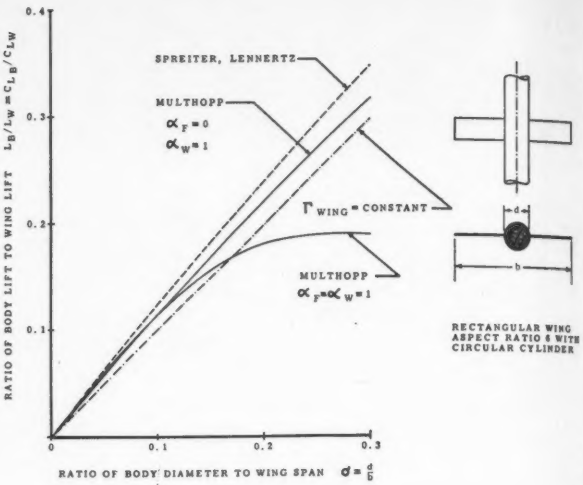


Figure 9.
Ratio of body interference lift to wing lift (Multhopp method).

In order to show the results of a calculation, the lift distribution has been calculated for a rectangular wing of aspect ratio 6 in mid-wing combination with a circular cylinder having a diameter of 20% wing span. Two cases have been considered: (i) $\alpha_F = \alpha_W = 1$, that is a combination without a wing incidence setting referred to the fuselage axis, and (ii) $\alpha_F = 0$, $\alpha_W = 1$, giving the distribution for a unit wing incidence setting (Figure 10). The distribution for the wing alone has been added for comparison. The overall lift coefficient is also drawn against angle of attack, for the wing alone, the combination without a wing setting, and for a wing setting of 5°. Note that it is the aerodynamic wing setting that is being considered. The setting angle is taken between the local zero lift lines, along the span, and the cylinder axis.

The limits of applicability of the method follow from

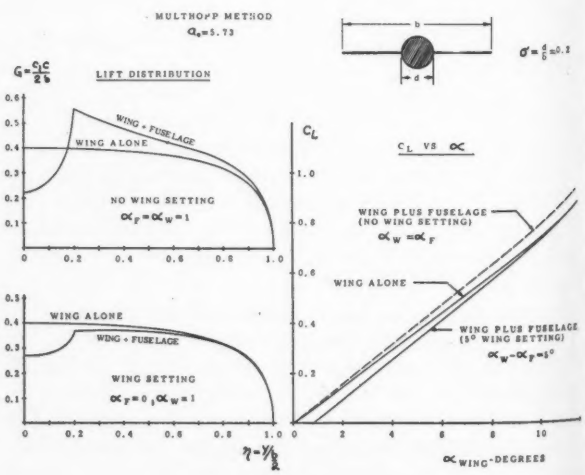


Figure 10.
Rectangular wing of aspect ratio 6 in mid-wing combination with a fuselage of circular cross section (body diam. = 20% span).

the assumptions on which the method is based. The application of the lifting line theory implies that the method can be safely applied only to larger aspect ratios, say $A \geq 6$, and to small body-diameter-to-wing-span ratios, say $\sigma \leq 0.1$. As extreme limits, for estimates, $A = 4$ and $\sigma = 0.2$ may be taken.

The Multhopp method may be extended, by simple devices, to cover wings of small aspect ratio and swept back wings, and to take account of the finite thickness of the wing at the body junction and larger chord-body diameter ratios. These refinements have been suggested by Weber, Kirby and Kettle,[4] and in some cases seem to give satisfactory results.

SPREITER'S THEORY AND THE METHOD OF LOW AND STONE

For wings of very low aspect ratio in combination with slender bodies a theory was developed by Streiter[5]. His theory is essentially based on the assumption that, at each station of the wing-body combination, the transverse flow can be regarded as two-dimensional, changing of course with the station under consideration. In this way the classical method can be applied in order to find the potential of the flow and, consequently, also the pressure at each point and the lift distribution. The theory, which is linear, treats delta wings of small aspect ratio in combination with various forms of slender bodies of revolution such as, for example, conical bodies, semi-infinite circular cylinders, etc.

The ratio of the body lift to the wing lift has already been shown in Figure 7 for a circular cylinder in mid-wing configuration. The result is independent of the aspect ratio, and so in the non-dimensional lift distribution $G = \frac{c_l c}{2b}$. According to this theory, the lift distribution over the body region has the form as given in Figure 11, where the distributions are plotted for $\sigma = 0.2$; 0.5; and 0.8. The broken lines show ellipses through the endpoints, for comparison. In Multhopp's theory the distribution was elliptical in the case of bodies of circular or elliptical cross-section; this was due to the fact that the potential in the fuselage region was approximated by using only the linear term. Figure 11 reveals that the lift distribution, according to Spreiter, differs more and more from the elliptical distribution the larger the ratio σ of the body diameter to the wing span becomes. However, the distribution approaches the elliptical form, if σ goes towards zero, so that here the relation to the Multhopp method is established.

Spreiter's theory was developed for very small aspect ratios. Consequently the resulting values strictly apply only to the limiting case $A \to 0$. For a wing alone, Spreiter's theory leads, in accordance with other theories, to a lift curve slope $\frac{dC_L}{d\alpha} = C_{L\alpha} = \frac{\pi}{2} A$, that is, $C_{L\alpha}$ changes linearly with the aspect ratio, and is independent of the wing planform. The actual change of the lift curve slope with aspect ratio as given by tests, and obtained by Weissinger[10 11] and Lawrence[6], is shown in Figure 12 for a rectangular wing. It is seen that the values resulting from Spreiter's theory represent the tangent to the actual curve at $A = 0$.

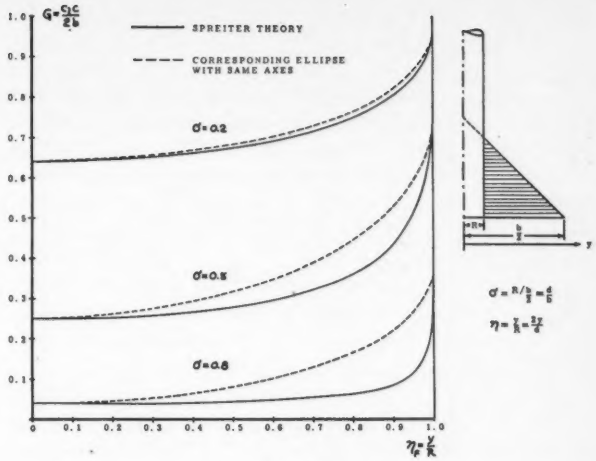


Figure 11.
Spanwise lift distribution on body for triangular wing-semi-infinite cylinder combination.

Based on Spreiter's theory, Low and Stone[7] suggested a practical method for determining the overall lift coefficients for a wing-body combination. The method was derived for rectangular wings of low aspect ratio, attached symmetrically to cylindrical bodies of circular cross-section. The lift (and likewise the pitching moment) is calculated as the sum of four components:

1) the contribution of the isolated wing,
2) the contribution of the isolated body of revolution,
3) the contribution of the wing due to the presence of the body, and
4) the contribution of the body due to the presence of the wing.

As pointed out, no lift distributions are obtainable from this method. The non-linearity with respect to the angle of attack, however, can be taken into account (according to Lawrence[6]), and also the effect of the boundary layer of the fuselage. In the present paper the method will be

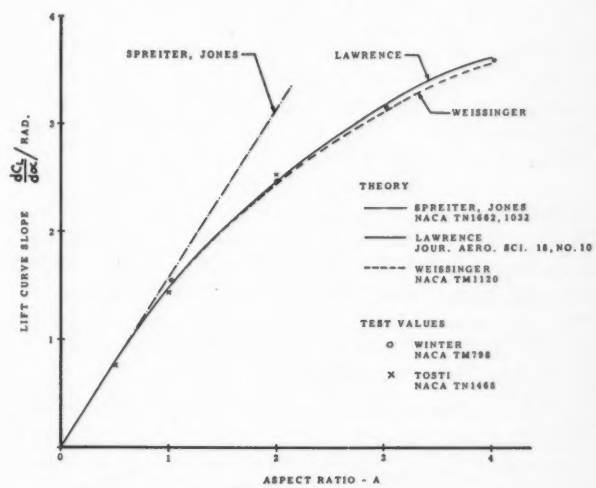


Figure 12.
Lift curve slope $C_{L\alpha} = \frac{dC_L}{d\alpha}$ for rectangular wings of small aspect ratio.

explained taking the linear part of the lift only, which means that, in the case of low aspect ratios, only small angles of attack are considered. Moreover, only the case of an infinite cylinder is dealt with, so that no contribution due to the isolated body occurs. It thus remains to calculate the lift of the wing due to the presence of the body and the lift of the body due to the presence of the wing.

The latter is found according to the Spreiter theory which yields the ratio of the body lift to wing lift, depending only on the ratio of the body diameter to the wing span. In order to find the lift of the wing, including the body effect, Low and Stone proceed as follows:

The upwash due to the body causes the angle of attack to vary along the span. The average angle is then calculated, and the lift coefficient of the wing is obtained by determining the lift curve slope of the exposed wing, assumed as isolated, and by applying the average angle of attack.

These two steps in the procedure, taking the average angle and treating the wing then as isolated, can only give an approximation. It is shown in Reference 12, that the lift due to the angle distribution is, in general, not equal to the lift due to an average angle along the span. The lift coefficients obtained with the average angle are underestimates. On the other hand, treating the wing as isolated, somewhat overestimates the results. The errors in these two steps, however, may cancel one another approximately, so that the final result may be in fair agreement with a more correct calculation.

PRACTICAL METHOD FOR CALCULATING THE DISTRIBUTION OF WING-BODY COMBINATIONS

It has been shown that the Multhopp method gives very good agreement with reality as far as large aspect ratios ($A > 6$) and small ratios of body diameter to wing span ($\sigma < 0.1$) are concerned. On the other hand, Spreiter's theory covers very small aspect ratios, for all ratios σ of body diameter to wing span. However, since the latter theory strictly applies only to the limiting case of zero aspect ratio, the absolute values are not correctly given for aspect ratios larger than 1, and the results must be reduced by a factor in order to get the correct lift slope. This limitation is overcome by the method of Low and Stone: their practical method can be applied to the complete range of A and σ, to find the overall lift values, but no lift distribution is obtained here.

It would be convenient, of course, to have a method which covers all possible configurations. It has been pointed out that the Multhopp method may be extended to also take into account small aspect ratios (by decreasing the sectional lift slope value). However, this and the other modifications suggested by Weber, Kirby and Kettle[4] do not make the method applicable to cases of large ratios of body diameter to wing span.

The present paper approaches the problem in another way, that is, by a simple analogy. Using conformal transformation, the Multhopp method was seen to lead to an equation for the circulation in the mapped plane. The equation has the same form as that for a wing alone, with the chord multiplied by the factor $\mathscr{R}$, and the wing setting angle along the span (relative to the fuselage axis) divided by the same factor. In symbols, the equation was

$$\mathscr{P}(\bar{G};\bar{p}) = \alpha_F + \frac{\alpha_W - \alpha_F}{\mathscr{R}}.$$

Since Weissinger's L-method gives satisfactory results for the entire range of wing aspect ratios, an anology may be used, and the equation of the lift distribution in the mapped plane written in the form of the L-method:

$$\mathscr{L}(\bar{G};\bar{\lambda}) = \alpha_F + \frac{\alpha_W - \alpha_F}{\mathscr{R}}$$

where $\mathscr{L}$ stands for

$$\mathscr{L}(\bar{G};\bar{\lambda}) = \frac{2}{2\pi}\int_{-1}^{+1}\frac{\frac{d\bar{G}}{d\bar{\eta}'}\,d\bar{\eta}'}{\bar{\eta}-\bar{\eta}'} + \frac{\bar{\lambda}}{2\pi}\int_{-1}^{+1}\frac{d\bar{G}}{d\bar{\eta}'}\,L[\lambda(\bar{\eta}-\bar{\eta}')]d\bar{\eta}'$$

with

$$\bar{\lambda} = \frac{\bar{b}}{c\mathscr{R}}$$

$$L(k) = \frac{\sqrt{1+k^2}-1}{k}.$$

It must be stressed that this is an analogy only. Similar suggestions have been made by Lawrence and Flax, who approach the problem with two somewhat different equations, noting that experiment must show which equation gives the more satisfactory results. (For theoretical considerations, see Reference 8). It will be seen, however, that the present formulation leads to results which are in good agreement with the other methods in their respective regions of applicability.

The application of the L-method does not involve any additional difficulties. Usually it will be sufficient to make the calculations with four points along the semispan. The results presented in this paper were all obtained in this way.

In some cases, and if greater accuracy is required, the calculation should be performed with 8 points along the semispan, as in the Multhopp method.

The interference lift of the body, due to the attached wing, can be obtained by using the relationship between body lift and wing lift distribution or by using the Spreiter-Lennertz results as an approximation, as explained above. If the lift-distribution is also required, the assumption can be made that it is elliptical if small ratios σ of body diameter to wing span are considered. For large values of σ, the Spreiter formula can be used. It must be noted, however, that the Spreiter formula applies only to the limiting case of zero aspect ratio, so that the values must be reduced in the way mentioned above. The only difficulty arising here, by reducing the lift values in the same ratio ($C_{L_B}/C_{L_{B\ \mathrm{Spreiter}}}$), is the fact that the value at the wing root, so obtained, will differ slightly from the value found by calculating the wing lift distribution. However, this limitation can easily be overcome.[12]

As an example, the results of the calculation are shown in Figure 13 for a rectangular wing of aspect ratio 2, in mid-wing combination with a fuselage of circular cross-section. Two cases have been treated here:

1) No wing setting, that is, the wing is aerodynamically untwisted along the span, and the zero lift lines of the profiles have the same angle of attack as the fuselage axis;

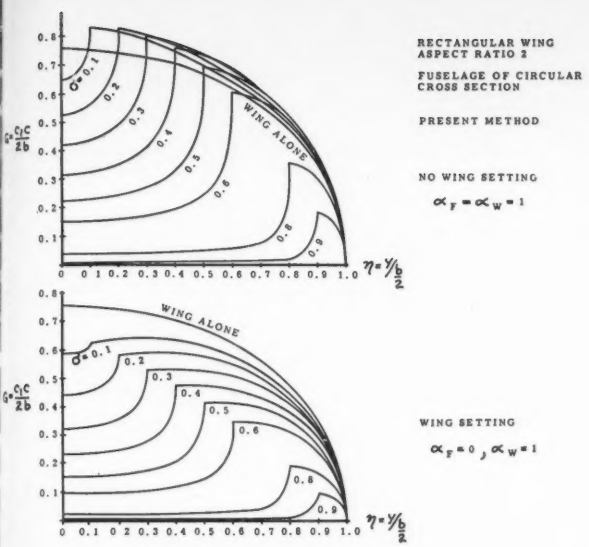


Figure 13.
Lift distribution along span of mid-wing configuration.
Present method
Rectangular wing $A = 2$
Fuselage of circular cross-section.

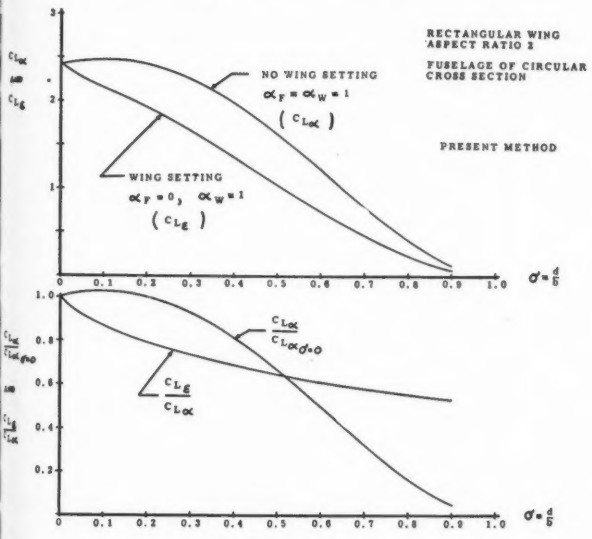


Figure 14.
Lift of mid-wing combination compared to wing alone.
Present method
Rectangular wing $A = 2$
Fuselage of circular cross-section.

2) A constant wing setting along the span, the angle of attack of the fuselage being zero. In both cases the distribution for a unit angle (one radian) has been determined. Figure 14 then shows the corresponding overall lift; both the absolute coefficients and the ratio of the lift of the combination to that of the wing alone ($\sigma = 0$) are presented.

COMPARISON OF THE PRESENT METHOD WITH OTHERS

The Multhopp method was seen to give satisfactory results for large A and small σ; the Spreiter method, on the other hand, was valid for very small A. The question arises whether and how closely the present method approaches the other ones in their ranges of applicability, so that the connection with the other methods can be established.

For this reason the case of a rectangular wing of aspect ratio 4, in combination with a fuselage of circular cross-section and a body diameter of 0.2 span, has been investigated. This case may be regarded as the extreme one for applying the Multhopp method and also the Spreiter method. The results are given in Figure 15 for

1) the Multhopp method,
2) the Spreiter theory with reduced values as explained above,
3) the present method.

The results of the present method and that of Spreiter show a satisfactory agreement; the Multhopp method, as expected, furnishes values which differ somewhat, mainly in the body region. However, as an approximation, the

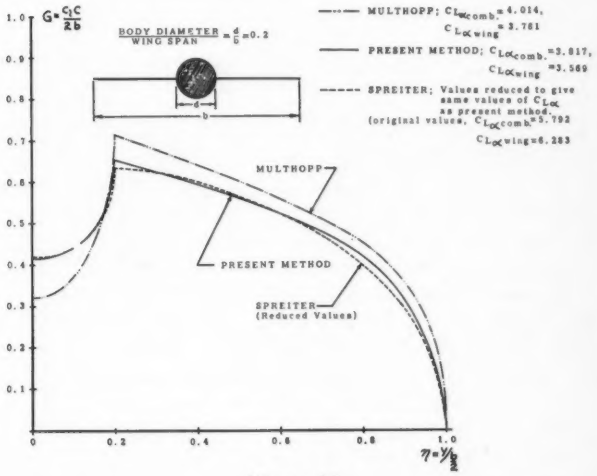


Figure 15.
Lift distribution of rectangular wing, aspect ratio 4, in combination with infinite body of circular cross section.

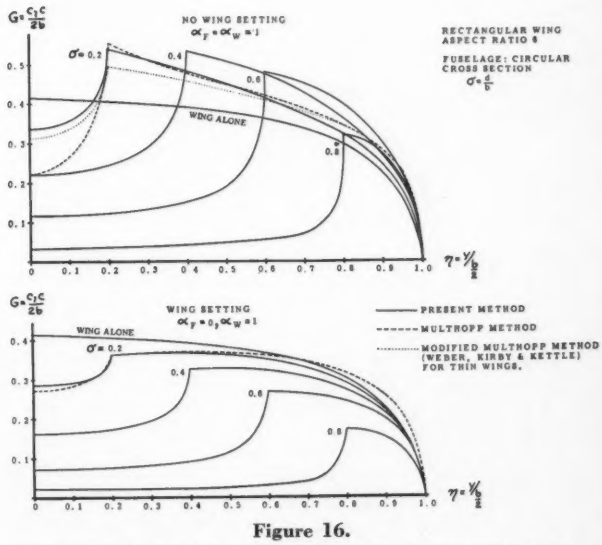


Figure 16.
Lift distribution of rectangular wing, aspect ratio 6 in combination with infinite body of circular cross-section.

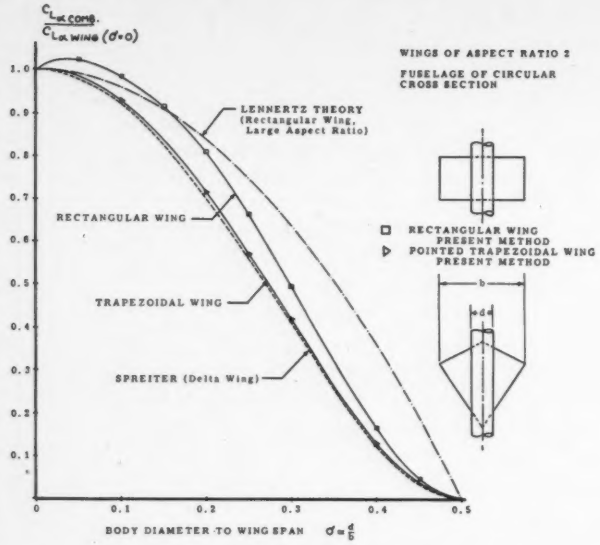


Figure 17.
Lift of mid-wing combination compared to wing alone. Wings of aspect ratio 2

result is tolerable in view of the fact that an aspect ratio of 4 is the extreme lower limit of applicability of this method. For an aspect ratio of 6, $\sigma = 0.2$, the agreement is more satisfactory, particularly for the case of a wing setting (Figure 16). For the case of no wing setting, $\alpha_F = \alpha_w$, some discrepancy remains. It may be noted here that the modified Multhopp method[3] gives a better agreement with the present method. As has been pointed out, however, the method is not applicable to large values of σ.

The ratio of the lift of the combination to that of the wing alone is shown in Figure 17 for wings of aspect ratio 2. The calculation has been performed for a rectangular wing and a pointed trapezoidal wing, for various body diameters. The agreement with Spreiter in the case of a pointed wing is satisfactory. The Lennertz curve,

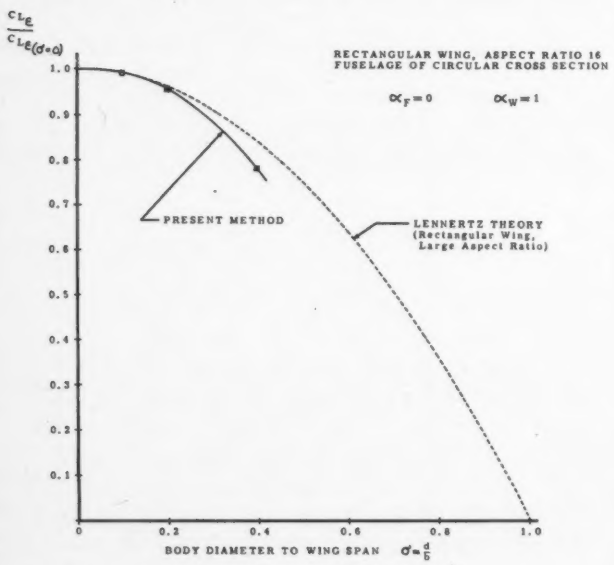


Figure 18.
Lift of mid-wing combination compared to wing alone. Rectangular wing of aspect ratio 16.

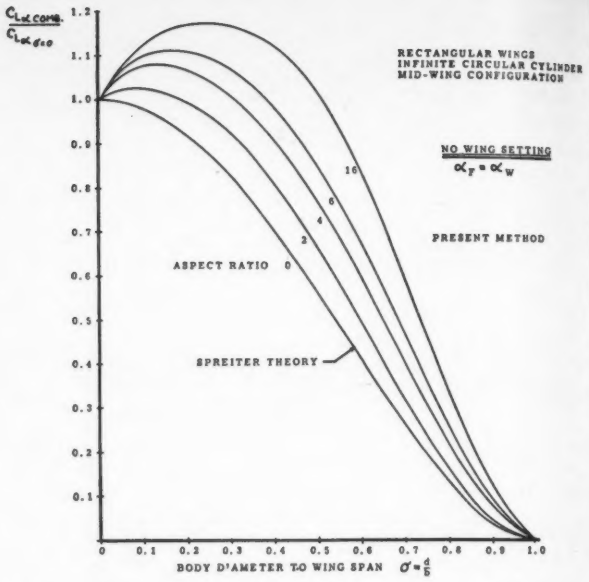


Figure 19.
Ratio of lift of wing-body combination to lift of wing alone.

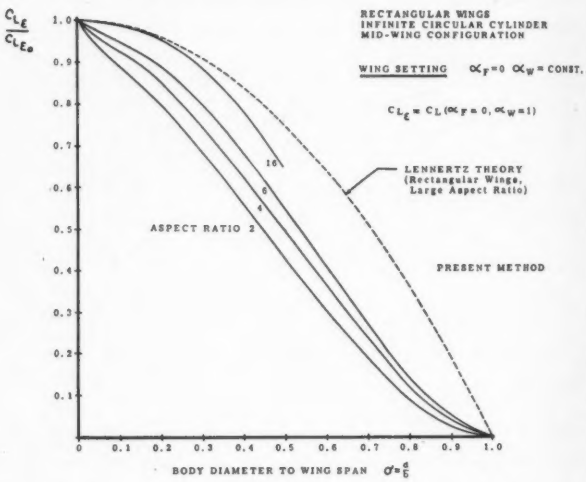


Figure 20.
Ratio of lift of wing-body combination to lift of wing alone.

derived for rectangular wings of high aspect ratio, has also been inserted for comparison, but no agreement can be expected here. If, however, the case of a wing of aspect ratio 16, $\alpha_F = 0$, $\alpha_w = 1$ is taken the results of Lennertz and the present method show better agreement (Figure 18).

The preceding comparisons have shown that the results of the present method approach those of the Spreiter theory for small aspect ratios. On the other hand, taking large aspect ratios, agreement with Multhopp's and Lennertz' results has also been obtained. In general, it can be said that the present method can be applied to the whole range of aspect ratios and ratios of body diameter to wing span, and shows good agreement with the other theories in the limiting regions in which they are valid and applicable.

In the following, some general results will be shown,

for example the influence of aspect ratio and taper ratio in the case of a fuselage having circular cross-section. For comparison only, the results for configurations with bodies of elliptical cross-section are also added. Finally, the case of partial span flaps is treated, and the theoretical results are compared with experimental data.

RESULTS

Effect of Aspect Ratio on the Total Lift

The example of a rectangular wing of aspect ratio 2, in combination with a circular cylinder, has shown how the total lift of the combination changes with the ratio of body diameter to the wing span. If the wing incidence is the same as that of the fuselage, the lift increases slightly with increasing body diameter to a maximum value and then decreases again. For the case of a finite wing setting, that is $\alpha_F = 0$, $\alpha_w \neq 0$, the lift decreases with σ. Now the effect of aspect ratio will be investigated. This has been done in the case of rectangular wings, and the result is presented in Figures 19 and 20. Here the total lift of the combination, referred to the lift of the wing alone (zero body diameter) is shown against the body diameter ratio for various aspect ratios. All curves have the same form; increasing aspect ratio is seen to increase the total lift values for all σ.

Effect of Taper Ratio

For this investigation, a wing of aspect ratio 4, in combination with a circular cylinder, has been chosen; the resulting lift distributions for various taper ratios are given in Figure 21. It is seen that the body effect becomes more pronounced with increasing taper; consequently the lift of the combination, referred to that of the corresponding wing alone (zero body diameter) decreases with increasing taper.

Bodies with Elliptical Cross-Section

In the present paper, only bodies with circular cross-section are generally considered. However, it follows from previous remarks that the calculation is possible for any cross-section, provided that the two-dimensional flow around such a cross-section has been determined. As an example, the results for an elliptical cross-section, in a mid-wing configuration, may be given here. The investigated axis ratios μ (vertical axis to horizontal axis) are 2, 1 (circle), and $\frac{1}{2}$. The lift distribution curves (Figure 22) indicate clearly that the body lift decreases with increasing ratio μ.

General Note on the Body Effect

In all results given above, the lift coefficient was referred to the basic wing area, that is the area of the wing with leading and trailing edge continued through the body region. If the values are based on the exposed wing area, which is obtained by joining the two wing parts outside the body at their root chords, the Spreiter theory for delta wings in combination with a circular cylinder yields a very simple result. Denoting the lift coefficients based on the exposed area by $C_{L^*_{WB}}$ for the wing-body combination, and $C_{L^*_{W\ exp}}$ for the exposed wing, without body interference, the following equation is obtained:

$$C_{L^*_{WB}} = (1+\sigma)^2 \times C_{L^*_{W\ p}}$$

that is, the lift coefficient of the combination, divided by the lift coefficient of the exposed wing, is a simple function of the body diameter ratio only. The question arises as to the relation in the case of any aspect ratio, and any wing form, in combination with a fuselage of circular cross-section. The results of the calculations due to the present method have been examined in this respect, and Figure 23 shows that the values of $C_{L^*_{WB}}/C_{L^*_{W\ exp}}$ for all combinations are close to the Spreiter curve; no appreciable influence of aspect ratio or wing planform can be found. (Note in this connection that the calculations were performed by using only four points along the span.)

It may be mentioned that Lawrence and Flax[8], using the lifting line theory, come to somewhat different results which show a slight influence of both aspect ratio and wing form.

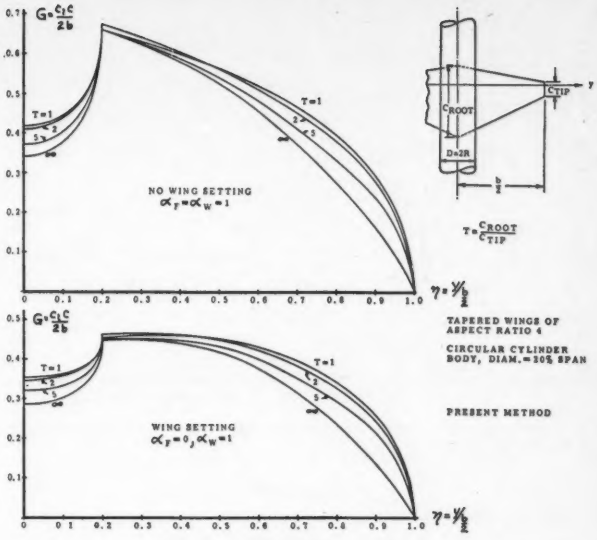


Figure 21.
Effect of taper on lift distribution on wing-body combination.

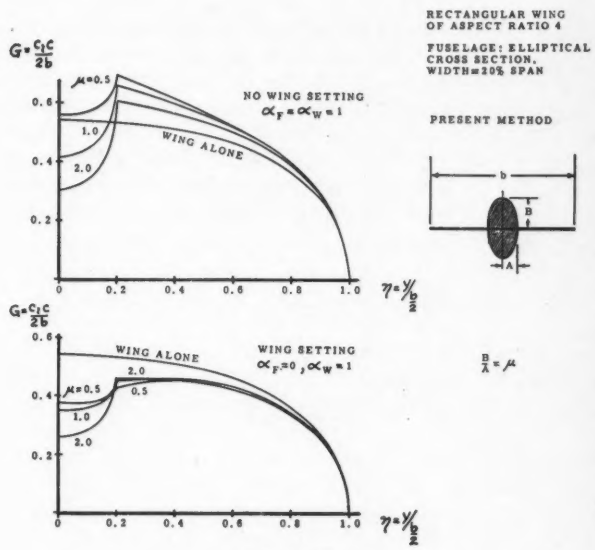


Figure 22.
Lift distribution on wing-body combination. Bodies of elliptical cross section.

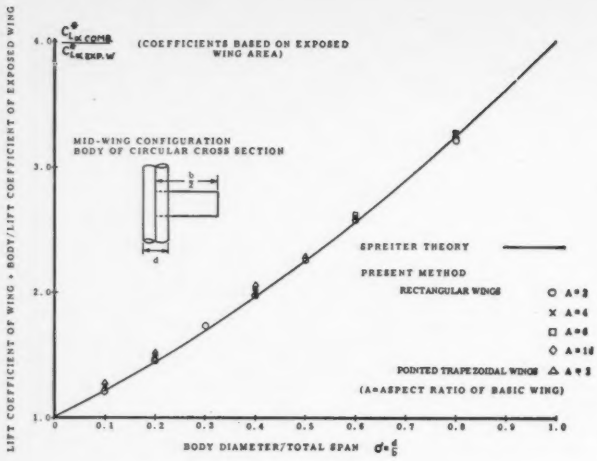


Figure 23.
Ratio of lift coefficient of wing-body combination to lift coefficient of exposed wing.

The general relation between the lift of the wing-body combination and the exposed wing which, according to the results of the present method, depends in the first order only on the body diameter ratio, is very valuable. It enables a quick and simple calculation of the total lift of a configuration. The lift coefficient of the exposed wing is easily determinable; the lift coefficient of the combination (based on the exposed wing area) is, in the case of a mid-wing configuration with a circular cylinder, obtained by multiplication of the wing lift coefficient by $(1 + \sigma)^2$.

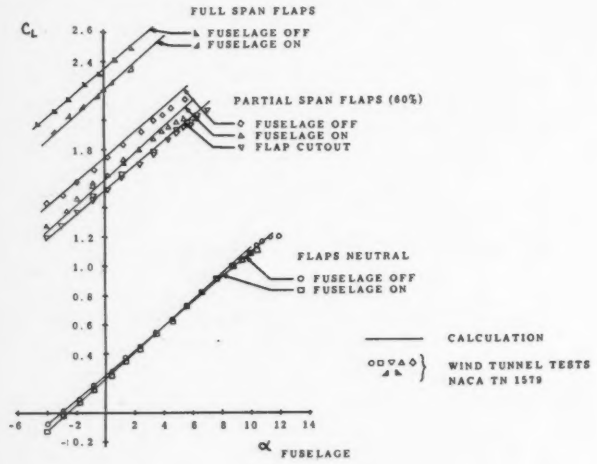


Figure 24.
Comparison—Tests and calculations of NACA 65-210 wing with and without double-slotted flaps and fuselage.

The Effect of Partial Span Flaps

The method outlined in the preceding sections can be applied to the case of partial or full span flaps without any new difficulty arising, since the deflection of a flap means merely a change in the twist distribution of the wing. In order to see whether and how closely the theory approaches experimental results, a sample calculation has been carried out in a case for which experimental results are available, that is, for the configuration of the previously mentioned N.A.C.A. TN 1579[1].

The calculations were carried out for all cases tested and all types of flaps; the results are shown in Figure 24 for the case of double slotted flaps. Since $A = 9$ and $\sigma = 0.0833$, the Multhopp method can also be applied here. The full lines give the theoretical results; the test data are represented by the symbols. Since the theory is linear and based on potential flow, separation effects near C_{Lmax} cannot be reproduced by theory; however, in the linear range, the agreement is quite satisfactory.

This is of interest in the case of partial span flaps, with reference to the remarks made earlier on the behaviour of the various types of flap, in conjunction with a body. Aerodynamically, in calculating the lift, only the change of the two-dimensional zero lift angle due to a flap deflection is of importance. In Figure 25, therefore, the theoretical results in the case of partial span flaps are compared with the experimental data for all three flap types. The agreement is satisfactory, and the calculation confirms the experimental result that the lift carried across the body at $\alpha_F = 0$ is not the same for all three cases.

The calculation now shows why the various flaps behave differently. If the zero lift line of the wing is parallel to the fuselage axis, that is, if there is no wing setting, the lift carried across the fuselage would be exactly the same for any flap effectiveness. However, the situation changes if there is a wing setting, as in the above example. This is illustrated in Figure 26, where, for the same example, the lift carried across the body is plotted against the flap effectiveness, $|\Delta\alpha_o|$. It is clearly seen that, the higher the flap effectiveness, the more lift is carried across the body. Figure 27 shows also the effect of the wing setting i_w for various flaps; with increasing i_w, the lift carried across always decreases, the rate of decrease becoming smaller, the higher the flap effectiveness.

It may be mentioned that, as a calculation shows, the lift carried across decreases with increasing taper ratio and decreasing aspect ratio.

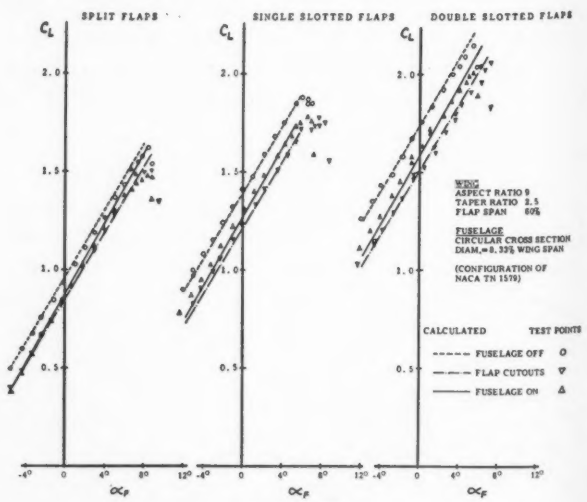


Figure 25.
Comparison of theoretical and experimental lift curves for a wing-body combination with partial span flaps.

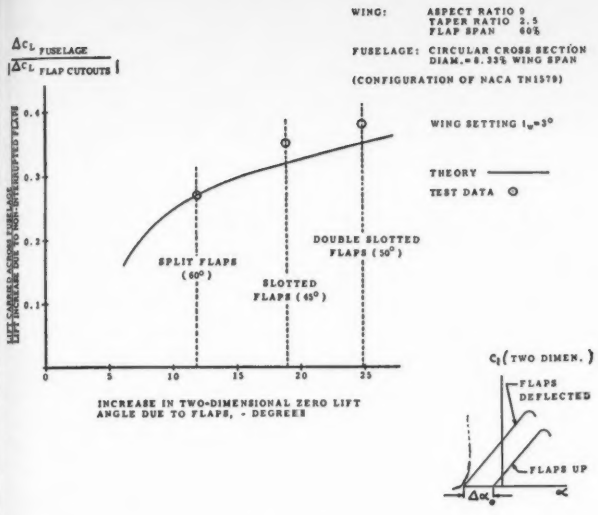


Figure 26.
Influence of flap effectiveness on lift carried across fuselage.

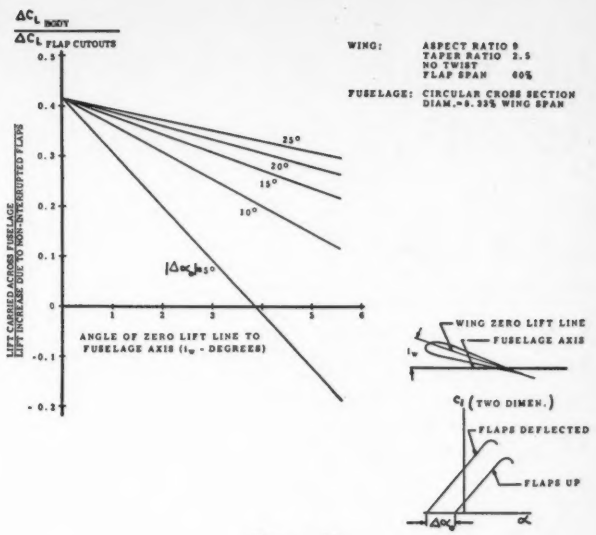


Figure 27.
Influence of wing setting on lift carried across fuselage.

CONCLUDING REMARKS

In the preceding chapters, a method has been suggested for calculating the lift distribution over an unswept wing-body combination in symmetric subsonic flow, and it has been shown that the method is in good agreement with other available methods in their respective limited ranges of validity. The present method has been explained and calculations have been made mainly for the case of a mid-wing configuration and a fuselage of circular cross-section, since the Spreiter theory and likewise the Low-Stone method apply only to slender bodies of revolution and mid-wing configurations without a wing setting. While the Spreiter theory, for these configurations, can only be applied to very small aspect ratios, the Low-Stone method does not give a lift distribution, and the Multhopp method can be used for any configuration of high aspect ratio but small body diameter ratios, the present method is applicable to the complete range of aspect ratios and body-diameter ratios, for any angle distribution along the span.

The suggested method is based on the same basic principles as the Multhopp method, which gives the same results as the present method if high aspect ratios and only small body diameters are considered. For conventional airplanes, with a high aspect ratio (≈ 9) and a body diameter less than 10% of the wing span, the Multhopp method can, in consequence, always be used successfully.

In general, the present method can be used with the simplification in assumptions as described in this paper; that is, for example, the wing thickness can be neglected. The comparison of calculations and experimental data, in a general case, had shown that satisfactory agreement between theory and experiment is obtained, even in the case of partial span flaps. In extreme cases, and if very accurate calculations are necesary for comparison, some refinements may be introduced as, for example, in Reference 4.

Although the method has been explained for bodies of circular cross-sections in mid-wing configurations, it is seen that any cross-section whatsoever can be dealt with. It is only necessary that the two-dimensional flow around such a cross-section be known. Similarly, the method can also be applied to wing-body configurations other than mid-wing combinations. In the present form, however, it can only be used for unswept wings.

The calculation of the lift distribution according to the present method does not involve any difficulty and can be carried out, for any configuration including wing setting, twist, and flap deflection, in approximately one computer-day if form sheets are used as given in Reference 12 for a mid-wing combination.

ACKNOWLEDGMENTS

The author wishes to express his thanks to Canadair Limited for the permission to present this paper and for making it possible to prepare the paper in the present form. Thanks are also due to the staff members of the Canadair Aerodynamics and Preliminary Design Sections for assistance in carrying out the sample calculations and in drawing the figures.

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CUSTOMER RELATIONS DURING AIRCRAFT PRODUCTION†

by E. H. Higgins*

Canadair Ltd.

SINCE points of view or opinions are moulded by the responsibilities and influences which closely surround an individaul or an organization, it is to be expected that the manufacturer will sometimes approach his problems from a somewhat different position than the user. However, in the broad view, both contractor and customer are mutually dependent upon each other. And in the end, all decisions from either source have one common aim—a better and more useful airplane.

When arriving at a decision which will affect an airplane under development or in production, it is generally agreed that the major factors which must be considered are as follows:

(1) The ability of the airplane to accomplish its mission
(2) Safety
(3) Quality: Including:
Serviceability,
Interchangeability,
Component Life,
Ease of Maintenance
(4) Cost
(5) Delivery

Most of these factors are inter-related. For example the airplane's ability to do a particular job is closely associated with both cost and delivery—by cost, since with a limited budget the number of aircraft which can be purchased is determined by the average cost per aircraft—by delivery, since an airplane can do a good job only so long as it is superior to, or at least competitive with, rival equipment in both performance and numbers.

Our occasional disagreements with the purchaser do not arise from any difference of opinion as to what the objectives are and do not develop from any difference of opinion as to what factors must be considered in order to accomplish the objectives. They do occur because of a difference of opinion as to the relative emphasis that should be placed on each of the factors involved.

The purchaser's decisions and directives can have a very substantial effect on manufacturing costs. It seems logical therefore, that personnel who are in a position to make decisions which relate to aircraft development or production programs should have some knowledge of the basic factors which determine such costs. The suggestion that an understanding of the fundamentals of production costs is not always present can be illustrated by the following typical questions:

(1) Why does a modification which apparently makes the airplane easier to build often result in an increase in price?
(2) Why does it cost so much to do a major aircraft repair job in comparison with the cost of a production aircraft?
(3) Why should the cost of spare parts and assemblies be substantially increased if they are not ordered in phase with the production program?

THE LEARNING CURVE

The answers to these and similar questions are all related to a phenomenon commonly known as the learning curve. The principles of the learning factor were first stated by Mr. T. P. Wright in 1936 and were developed under his guidance during World War II by the U.S.A.A.F. and the major U.S. aircraft manufacturers. It had, of course, been apparent for some time that the direct labor man-hours per airplane declined as the cumulative number of airplanes produced went up. What was not recognized was that this rate of improvement could be predicted with remarkable accuracy.

The rate of learning which was found to hold true from World War II data and which is still used today, with some refinements, is known as the "80% learning curve". The basic formula is simply that each time the number of aircraft produced is doubled, the number of man-hours required per aircraft is reduced by 20%. As an illustration, if the first aircraft produced took 100,000 man-hours the second would require 80% of 100,000 or 80,000 man-hours; the 4th would require 80% of 80,000 or 64,000 man-hours; the 8th would use 51,000 and so on until at the 100th airplane we are down to 22,000 man-hours and by the 1000th only 11,000 man-hours are required per airplane or only 11% of the direct labor cost of the first airplane produced.

The surprising fact, which is now supported by a large volume of data on actual performance, is that, under normal conditions, the learning curve factor in an experienced aircraft company rarely strays more than 2-3% away from the 80% rule. The theory behind the rule is perhaps not so clearly and exactly defined as the rule itself. The most evident factor is, of course, that the worker learns as he works and the more often he

†Based on a paper read to the RCAF Staff College, Toronto, in January 1955.

*Chief Project Engineer.

repeats an operation the more efficient he becomes and the fewer are his mistakes which create rejections and reworks. However the learning process is not confined to the direct worker alone but applies also to the administrative functions.

There must be a continuous program of improvement which begins with the correction of engineering and tooling errors and progresses to improvement of engineering, tooling, processes, plant layout, production control, quality control, procurement and management and labor morale. All of these management or overhead functions add to the worker's learning rate by making his work easier to do and by reducing idle or wasted time. Now a very high rate of learning in the initial phase of a production program could, in some cases, be traced to an initial lack of efficiency which left more scope for improvement. However, this cannot last very long and the efficiency of a manufacturing organization can soon be determined by its ability to maintain a rate of improvement close to or better than the 80% standard.

Progress down the learning curve can of course continue smoothly only so long as the airplane remains substantially unchanged. Modifications create new parts, assemblies and procedures for which the position on the learning curve is the same as for the first airplane. Minor changes introduced at a reasonable rate and with adequate time allowance for engineering, tooling, planning, procurement, manufacture and proving can usually be introduced without major disruptions in the learning rate. Major modifications do, however, move us back up the curve in proportion to the number of new parts and assemblies which are suddenly introduced.

A typical learning curve for an aircraft in production at Canadair is shown in Figure 1.

This curve shows the man-hours per airplane which were expended over the first 100 aircraft in the program and clearly indicates the dramatic improvement which takes place in the early stages of production. The man-hours for the first airplane are shown here as 100% and

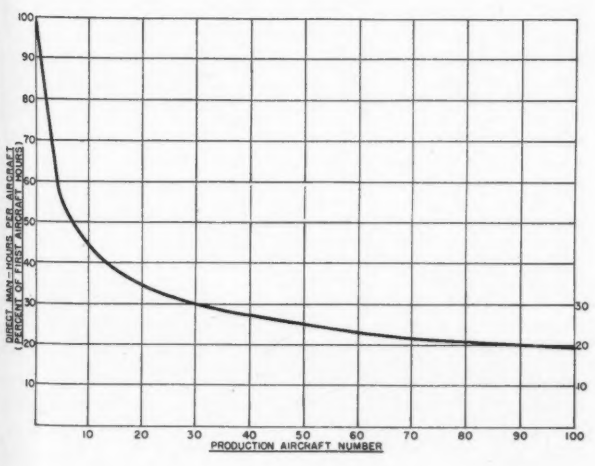


Figure 1
Learning curve: Aircraft 1 to 100.

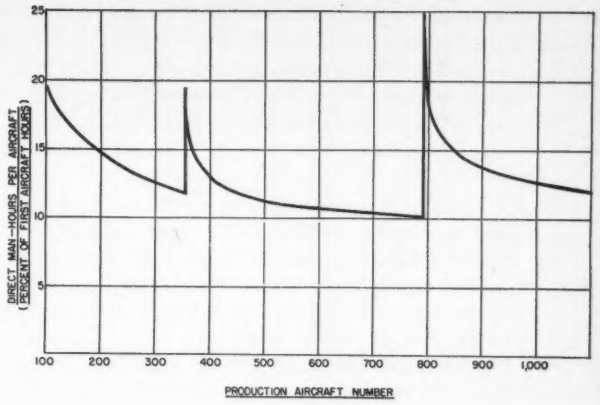


Figure 2
Learning curve: Aircraft 100 to 1,000.

it will be seen that at the 10th airplane the unit man-hours were reduced to 44% and at airplane 100 we were down to 19.4% of the first aircraft man-hours.

Figure 2 shows the unit man-hour curve from aircraft 100 to 1000. The man-hours continued to drop along the basic curve until at airplane 352 we were down to 11.9% of the first airplane man-hours. It is evident that, at this point, something happened because at airplane number 353 we were back up to 19.4%, or the same point of the curve as we had previously achieved at the 100th airplane. What happened was the introduction of a number of major modifications including:

(1) A redesigned pilot's windscreen structure;
(2) Introduction of a power operated nose landing gear emergency extension system;
(3) Structural provisions for a higher thrust engine;
(4) A redesigned air-conditioning system.

In addition a substantial number of minor modifications were scheduled for this same change point.

The production then continued from aircraft 353 to 791 without further major changes and by aircraft 790 we had achieved a new low of just over 10% of the first airplane man-hours. The learning curve rate during the first few aircraft in this series appears to be unexpectedly fast but can be explained by the fact that on the new portions of the airplane the reduction in hours between airplane 353 and 354 is 20% while for the rest of the airplane, on which a great deal of learning had already been accomplished, a further 20% reduction could not be anticipated until the quantity had once more been doubled or at airplane 706. The effect of the new initial learning requirement does, however, soon decline to a small increment and between aircraft 400 and 790 we had almost regained contact with the original curve.

At airplane 791, however, a new engine, and the associated major modifications to the airframe and systems, was introduced. Since the proportion of the airplane which was new, was much higher than at the previous major change point, the immediate jump in man-hours was substantially higher and the rate of recovery more rapid.

Returning to the three questions which were set forth earlier, it is now apparent that the answers are:

(1) A modification which may appear to make the airplane easier to build will normally increase the cost of the airplane for some period because each new item starts off at point zero on the learning curve.

(2) A major repair job may cost more in man-hours than a complete production airplane because the repair work is at the start of a learning curve. To the extent that repairs are the same or similar to previous jobs by the same people, a learning factor will, of course, apply.

(3) If spare parts or assemblies are not produced at the same time as the corresponding part or assembly in production, the man-hours will be increased to the extent that the item is different from the current production part on which the learning has been accumulated.

QUALITY CONTROL

Negotiations leading to a compromise between the various factors which affect the final product is a day to day operation in the field of Quality Control. The manufacturer, when faced with a situation where a completed part or assembly deviates to some degree from drawing requirements, is likely to recommend action which will, first of all, avoid any significant reduction in airworthiness and beyond that point will be based on a reasonable compromise between quality, operational suitability, cost and delivery.

In actual practice, action on rejected parts and assemblies is taken in two steps. The rejections are first of all referred to a Material Review Board made up of representatives of Quality Control, Manufacturing, Engineering and the customer. The function of this board is to determine the disposition of the rejected components, and may result in the part being accepted "as is", reworked, or scrapped. A second group known as the Corrective Action Committee reviews all repetitive rejections and ensures that action has been taken, or will be taken, to reduce the probability of further rejections for the same reason.

Before discussing further the differences in view points which commonly appear under the general heading of quality I would like to outline the magnitude and sources of the problem of quality control. We have seen by the nature of the learning curve in the aircraft industry that there is a large element of human skill and education in our operations. It follows automatically that there must be a large element of human error—and there is. The problems of quality control are first of all to ensure that errors are detected and corrected and secondly that they are reduced to a minimum level consistent with human fallibility.

The ratio of quality control staff to direct labor staff in the aircraft industry is substantially higher than is required in the manufacture of consumer products for the following reasons:

(1) the tremendous complexity and high dollar value contained in each cubic foot of the product;

(2) the severe safety requirements;

(3) the high degree of susceptibility to damage which is a consequence of the extreme importance of minimum weight and minimum space or size;

(4) the constant struggle against obsolescence which results in a continuous stream of changes—as an example more than 50,000 drawing changes have been issued on the F-86 contract since the first aircraft was completed;

(5) the relatively elementary degree of tooling employed in comparison with say the automotive or home appliance industries. The human error content certainly could be substantially reduced by a major increase in tooling. This is not, however, an acceptable solution simply because the cost would become prohibitive and the time required to develop and prove the tooling would be unacceptable to the customer.

In summary, therefore, we are dealing with a product which is relatively complicated and flimsy, in which the installations are crowded and inadequately accessible, which is continually changing, and for which a relatively low level of tooling control is provided. On top of these handicaps the need for a very high level of quality control cannot be compromised because of the severe requirements for safety and reliability and because the product is very expensive.

Under these circumstances it would be foolish and unrealistic to plan a quality control operation on the assumption that errors will be eliminated. Instead the organization must be directed toward discovering all important errors, correcting the source of errors to the extent that this is practical, and finally making the maximum use of rejected parts consistent with maintaining a satisfactory level of safety, operational suitability and quality. The scale of the problem can be realized by assuming that each direct worker makes only one mistake each month. At our present employment level at Canadair this would mean a total of 800 rejections per week.

Our differences with the customer in the face of the overall problem can be related, first of all, to the assessment of a condition in terms of airworthiness, safety, operational suitability, and quality which often cannot be exactly defined. When agreement has been reached on the definition of the condition and the effect on the various factors which the proposed rework will have, it then becomes necessary to weigh the reduction in quality which the action proposed by the company may entail against the cost and delay which may be involved by scrapping the component or by a more extensive rework procedure.

It is perhaps remarkable that this material review procedure is, in general, a fairly smooth operation. There is an almost inexhaustible supply of reasons for differences of opinion, from which friction can develop and grow. As is usually the case, however, the more often opinions are exchanged the more often is there a common approach.

The manufacturer has very strong incentives to strive for a reduction in rejection rates and a general

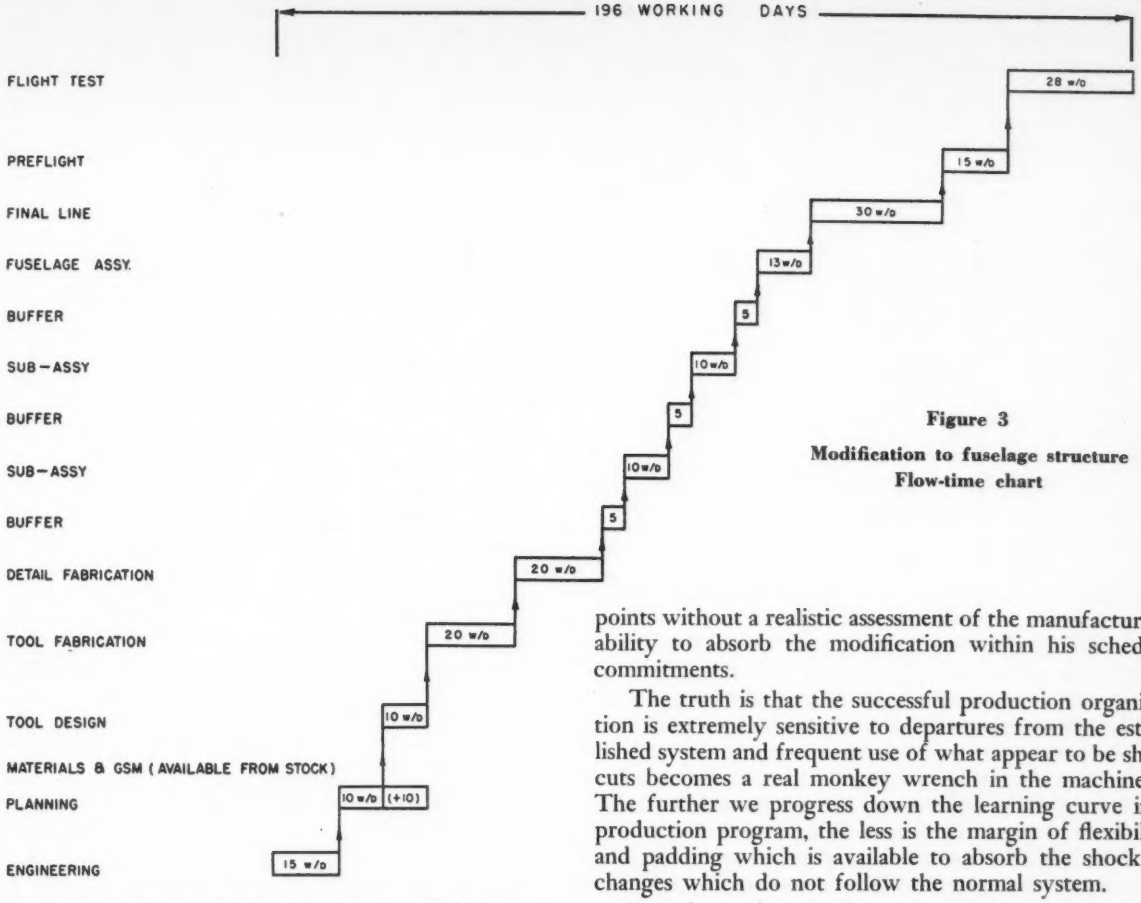


Figure 3

Modification to fuselage structure
Flow-time chart

improvement in quality since such action will improve his cost and delivery performance in addition to enhancing his reputation for quality. Both factors are essential to his continuing livelihood.

FLOW-TIME

One of the most frequent questions we hear is "why does it take so long to introduce a modification into a production line?"

In the first place, as every customer knows, it is possible, in individual cases, to assign the most competent personnel, short cut the routine of the paper mill, rob production stores for materials, pay premium rates for overtime at the purchased parts suppliers' plants, arrange for air express deliveries, and finally interrupt the production line sequence and apply maximum overtime until the pipe-line is full and the modification is backed up to the most efficient assembly positions. When such measures are applied the flow-time for introduction of a change can be cut at least in half and in the circumstances where the modification is mandatory for flight we have in fact taken such action.

If any attempt were made, however, to apply such measures as a standard approach or even as a frequent procedure, the entire system would dissolve into confusion, inflated costs and a complete breakdown of the delivery schedule. This conclusion is well supported by history in cases where the purchaser has been permitted to declare open house on changes and to specify change points without a realistic assessment of the manufacturer's ability to absorb the modification within his schedule commitments.

The truth is that the successful production organization is extremely sensitive to departures from the established system and frequent use of what appear to be short cuts becomes a real monkey wrench in the machinery. The further we progress down the learning curve in a production program, the less is the margin of flexibility and padding which is available to absorb the shock of changes which do not follow the normal system.

In so far as plant size is concerned, there is little doubt that an organization of one or two hundred people can do a small job faster than one of several thousand people which is organized to accomplish the primary task of a major aircraft production program. Size in itself is a handicap, and the greater the number of people engaged in one program, the greater is the need for establishing the standard procedures and systems which make up the paper mill. (For this reason we do, where possible, split off the small jobs into an experimental shop, or repair and overhaul shops which are to a large extent independent of the production organization).

It is therefore apparent that the normal system must be employed for the introduction of all but the most critical modifications. However, let us review the steps and the flow-times which apply to a relatively simple modification which affects primary structure. The change could be, for example, a redesigned frame in a center fuselage (Figure 3).

We will assume, to start with, that there has been no delay in obtaining the approval for the change, and that engineering personnel can be immediately assigned. This starting point is shown as day zero.

Since the change is straightforward, an engineering schedule of 15 days should be possible including stress check and completion of production drawings. (It should be noted that the time required for development of a change and the delays in obtaining customer approval often account for a substantial proportion of the total

flow-time and the assumptions made here are seldom achieved in practice).

Release of the drawings through engineering records and reproduction requires a further 5 days.

Manufacturing planning group prepares the part cards which notify procurement of material and purchased parts requirements, tool orders which specify tool design and fabrication requirements and production orders which define the manufacturing processes for the detail parts and change the process instructions for each sub-assembly and major assembly which is affected. In addition, corrected parts lists are issued which record the next assembly position for each part and notify production of all the parts required for each sub-assembly or assembly. Corrections are finally made to each assembly Operation Index. These forms travel down the assembly line to record completion and inspection of each installation and functional test in each aircraft. These procedures are completed to the point where tool orders can be released in a further 10 days.

Material supply can be a critical factor in the time cycle, particularly if extrusions, castings, forgings or non-standard raw material is required. Normal procurement times run anywhere from 6 to 12 months. We will assume in this case, however, that materials can be drawn from stock and replaced in time to meet other production requirements.

Tool Design prepares a Tooling Detail Master, designs the routing templates and hydro-press die, and modifies assembly jig drawings as required to accept the new detail part. Ten working days are allowed for these steps.

Tool Fabrication manufactures the routing template and hydro-press tool in a further 20 days. We will assume that sub-assembly and assembly tools can be reworked at the change point without delaying production or adding to the total time cycle.

In a further 20 days sample parts are produced for tool proving, tools corrected and detail parts manufactured and delivered through production stores to the sub-assembly shop. Thus, after approximately 4½ months, the change has been incorporated in production at the proper sub-assembly stage.

From this point we have entered the normal production sequence which, at one aircraft per day, requires a further 106 working days to progress through sub-assembly, fuselage assembly, final assembly line, pre-flight, flight test and delivery.

For the relatively simple structural modification, therefore, a total flow-time of 181 working days is required with no allowance for mistakes or delays between each of the steps described. Since mistakes and delays always do occur a further "buffer" allowance of 15 days would be added to the schedule.

The total time cycle from the date the change is requested to the time the first aircraft incorporating the change is delivered now adds up to approximately 10 months. This would be the normal flow-time for this particular case. As stated previously, it *can* be done faster in isolated cases. It cannot be done faster in *all* cases or even many cases if you wish to continue to have your airplanes delivered on schedule and at the low level of cost which we have achieved.

SELECTION OF EQUIPMENT

The aircraft manufacturer has learned through experience to take a realistic approach to scheduling his work which is based on actual experience rather than enthusiasm. We are often disturbed, therefore, by evidence that the customer's selection of equipment for installation in production aircraft is not always based on a similar assessment.

There are, of course, very strong incentives for specifying the black-box which, although still under development, shows every expectation of being greatly superior to the service proven equipment which is presently in production. Unfortunately the obvious potential advantages of the new equipment very often encourage an optimistic forecast of the time required to complete the development and service testing, issue the production order, and then complete production design, tooling, manufacture and delivery. The result is an airplane which cannot accomplish its mission either because the item of equipment has not been delivered at all, or because it does not meet its specified performance or cannot be kept serviceable.

There is only one good method of estimating the date when serviceable equipment will be available from production and that is to base the estimate on the actual time span for other similar items. The history of previous programs is not affected at all by the emotional influence of over-optimism.

CONCLUSION

I have discussed four general subjects with respect to which differences in viewpoint, or a lack of common understanding lead to disagreements between the manufacturer and the user. There are many other aspects which require frequent negotiation and I am sure there are many cases where the manufacturer's approach to a problem does not give sufficient consideration to the general experience and particular difficulties associated with operating the airplane in service. Since no one person can hope to be an expert on all the factors which relate to the production and operation of aircraft, no single individual can be expected to give the proper weight to each of the factors involved and independently arrive at the ideal solution. Each decision is a compromise and must be derived from the opinions and knowledge of several people within the customer's and the manufacturer's organization. There is no disagreement which cannot be resolved through meetings between the two representatives. The arguments which do not get settled are those which are conducted by correspondence or originate from an arbitrary directive which is issued without prior consultation. Relations between the user and the manufacturer can be improved to the benefit of both by continuous exchange of knowledge and opinion. The product must reflect the operational experience and planning of the customer, balanced against the production experience and planning of the manufacturer. This balance can be realized only by close and continuous personal liaison.

CRASH-FIRE RESEARCH WITH JET AIRCRAFT†

by I. Irving Pinkel*

Lewis Flight Propulsion Laboratory, N.A.C.A.

SUMMARY

Recognizing that much of the earlier crash investigation work on reciprocating engined aircraft still applies to turbojet engined aircraft, the author reviews the problems peculiar to the jet engine installation and points out that chief of these lies in the fact that, having no propeller to strike the ground, a jet engine continues to rotate after a crash and to draw quantities of air and combustibles through it. He examines the chief sources of ignition inside the engine and explains that if they can be rapidly cooled the likelihood of fire is greatly reduced. On the postulation that adequate cooling and steam-blanketing can be achieved by the use of only a few gallons of water selectively applied to the ignition sources within the engine, the author concludes by describing some full-scale crash tests, demonstrating the effectiveness of this technique.

RESEARCH on the origin of crash fires, conducted by the NACA from 1949 to 1953, covered airplanes powered with reciprocating engines[1, 2]. This report reviews the full-scale research with jet aircraft that followed the work with reciprocating-engine aircraft.

INVESTIGATION

The work on the origin of crash fires includes a full-scale crash phase along with supporting laboratory studies. In the full-scale phase, fully instrumented aircraft are accelerated from rest under their own power and guided into a crash barrier where the damage imposed is typical of take-off or landing accidents in which large quantities of fuel spill. This accident is studied because it occurs at low airplane speed and the chance is good for passenger survival of the crash impact.

The work with the reciprocating-engine aircraft showed how the airplane combustibles – oil, fuel, and hydraulic fluid – spill in a crash, the movement of the spilled combustibles to the ignition sources to start the fire, and when and where these ignition sources are likely to appear. Much of what was learned applies to turbojet aircraft. However, there are some additional considerations, chief among them being that the turbojet has no propeller to strike the ground and bring the engine to rest. Therefore, the engine continues to run after the crash and draw large volumes of air into the engine inlet. Crash-spilled combustibles can be sucked into the engine inlet with the air and ignite explosively within the engine.

TEST STAND

This explosive ignition was studied in detail with a turbojet on the test stand. Motion-picture sequences showed the flames that issued from the engine following the ignition of fuel sucked into the operating engine with the intake air. Scraping of the compressor blades on the compressor case produced flakes of magnesium burning in the flaming fuel. Flames also appeared at the engine tail pipe. The flames issuing from the engine inlet and tail pipe could reach fuel spilled around a crashed airplane and set the airplane on fire.

Loss of the compressor and other engine components sometimes accompanied this explosion. The compressor damage produced by the explosion just described is shown in Figure 1. Many of the missing compressor blades piled up at the inlet screen.

The test-stand studies showed that the combustibles sucked into the engine can be ignited by the continuous flame in the engine combustors or by the hot metal of the engine interior for a short time after the combustor flame is extinguished.

CRASH TESTS

To check these results in actual crash, turbojets were pylon-mounted to the wings of a cargo airplane, from



Figure 1.
Damage to compressor rotor

†Paper read at the I.A.S./C.A.I. International Meeting in Ottawa, on the 4th November 1955.

*Associate Chief, Physics Division

which the reciprocating engines were removed, to simulate one type of the jet bomber. The operating jet engines powered the airplane into the crash barrier. The airplane carried 1,000 gallons of JP-4 fuel. Arrangements were made to stop the fuel flow to the engines at the moment of crash impact. The flame in the engine combustor was thus extinguished, leaving only the hot metal of the engine as the ignition source.

The crash of the simulated jet bomber was studied in another motion-picture sequence. After the airplane passed through a crash barrier, fuel spilling from the damaged wing tanks was sucked into the engine, where it ignited on the hot metal of the engine interior. Flames issuing from the inlet and tail pipe ignited the fuel spilling from the wing and set the major fire.

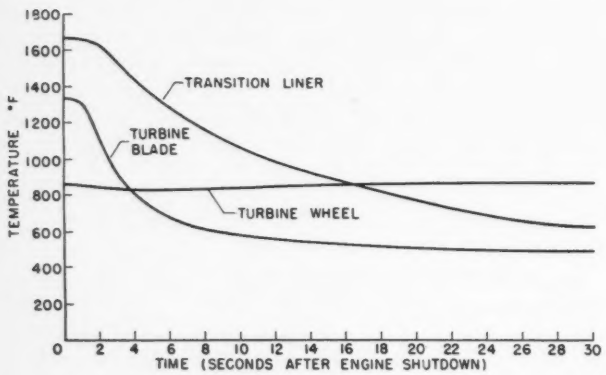


Figure 2.
Normal temperature decay of turbojet components

IGNITION SOURCES

With the ignition of crash-spilled combustibles by the hot engine parts demonstrated on the test stand and in full-scale crash, a search for these ignition sources was made. The search began with a measurement of the metal temperatures in the operating engine. Some characteristic engine component temperatures obtained are shown along the ordinate in Figure 2. The turbine blades and the hottest parts of the transition liner run about 1,300° and 1,700°F., respectively. The turbine wheel, which is not in the main gas stream, heats by conduction from the rim, and its hottest parts are about 900°F. When the combustor fuel flow is cut off (at zero on the abscissa scale), the temperature of the engine elements in the now relatively cool engine air stream decreases rapidly. The temperature of the turbine blades falls to 800°F. in 5 seconds, and the transition liner cools from 1,700° to 800°F. in 20 seconds. However, the turbine wheel is not in direct contact with the main engine flow and hardly cools at all. In fact, parts of the turbine wheel are hot enough to ignite JP-4 fuel 30 minutes after engine shutdown. In general, this temperature survey of the engine showed that all the engine metal downstream of the combustor is above the ignition temperature of JP-4 for varying periods of time following fuel shut-off.

When the problem of what may be done to reduce the likelihood of crash fire is considered, it is evident

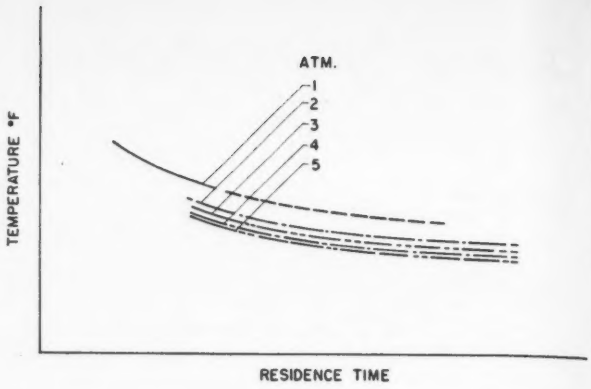


Figure 3.
Residence time for hot surface ignition

at once that provision should be made to shut-off the fuel flow to the engine combustor when crash occurs. In this way, the continuous flame in the combustor is eliminated as a positive ignition source. In the remainder of this discussion, it is assumed that the engine is equipped with a crash-sensitive fuel valve that cuts off the engine fuel flow. However, in view of the engine metal temperatures just described, the question arises: Are all of the hot engine components downstream of the combustor potential ignition sources in a crash? If this should prove to be so, then fire prevention in crash would require that a formidable weight of fire-extinguishing agent be mixed with all the air entering the engine. The extinguishing agent would have to be discharged into the engine at the moment of crash impact and continue to flow until the engine rotor coasts to rest.

CONTACT TIME AND PRESSURE

In the present approach to reduction of crash-fire hazards cognizance is taken of the fact that ignition of hydrocarbon atmospheres by hot surfaces is not instantaneous. The contact time between the combustible atmosphere and the hot wall required for ignition varies with wall temperature and atmospheric pressure in the manner shown in Figure 3. The required contact time increases with decreasing wall temperature and decreases with increasing pressure. Since the gas pressure is higher in the combustor than elsewhere in the engine, contact time and wall temperature required for ignition are lowest here.

Because of the high gas velocity through the engine, the combustible atmosphere flowing through the engine has insufficient contact time with the bulk of the hot metal surfaces for ignition. However, there are a few zones within the engine where sufficient contact time is possible. These zones are shown on the engine in Figure 4. Moving in the direction of flow, the first ignition zone is located at the combustor dome. Here a portion of the engine air is caused to recirculate by design and form a zone of reduced translational speed. Likewise, in this region residual flames linger briefly as the fuel flow is shutting down after crash impact. Crash-spilled combustibles sucked into the engine inlet arrive here under pressure and well mixed with the air by the compressor.

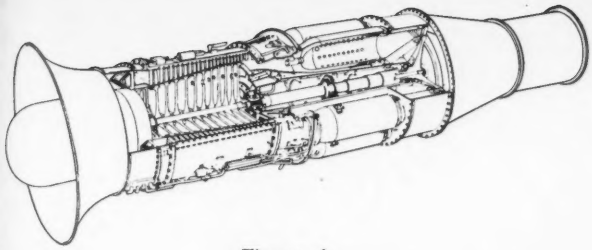


Figure 4.
Turbojet cut away

Whereas the gas velocity along the inside wall of the transition liner is too high for ignition, the small amount of gas diverted from the combustor to cool the outside surface of the transition liner has sufficient contact time to ignite. The outside wall of the transition liner is the second ignition zone.

The air drawn from the compressor for cooling the turbine wheel can bring with it the combustibles sucked into the engine inlet. A relatively long residence time is available, and ignition is likely. Also, this combustible mixture may enter the vent holes in the base of the internal tail cone and ignite on the hot walls of the quiescent interior. These vent holes are shown in Figure 5. Notice the damage to the tail-cone diaphragm produced by an internal ignition of the type just discussed.

WATER COOLING

These four ignition zones are all that were found within the engine. Fortunately, these zones are small, and it appeared feasible to cool them by water streams. This method was tried successfully in the test-stand engine. The water system for the combustor-liner dome shown in Figure 6 is a typical example of the plumbing required. Mounted concentric with the fuel nozzle is a toroidal water duct containing spray holes for injecting water into the combustion zone and holes for spraying water over the combustor liner. A total of 2 gallons of water, discharged in 4 seconds, is used for all combustors

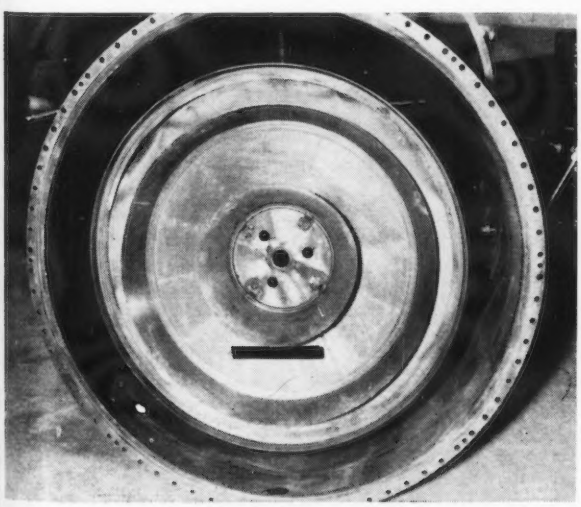


Figure 5.
Inner cone baffle plate

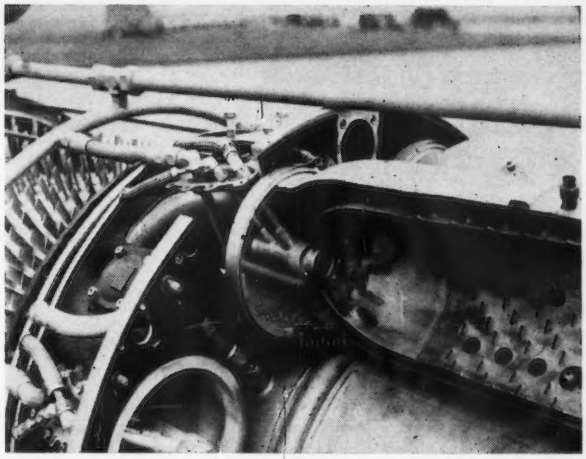


Figure 6.
Combustion chamber dome water nozzle

of a J47 engine. All the transition liners are cooled similarly with simple plumbing by 1 gallon of water. One gallon of cooling water for each face of the turbine wheel is delivered to the hub and spread centrifugally by wheel rotation. A small water spray into the interior of the inner tail cone generates sufficient steam to maintain an inert atmosphere. Since oil or fuel spilled on the outside wall of the tail pipe ignites quite readily, 2 gallons of water are used here.

The cooling of the turbine wheel, provided by the water, is shown by the data in Figure 7. This figure gives the temperature at the surface of the hottest part of the wheel. The turbine wheel is selected to illustrate the water cooling because its large heat capacity makes it the most difficult engine element to cool. At zero time, the fuel to the engine combustor is turned off and the water spray comes on. Notice that the turbine wheel cools quite rapidly at first to temperatures below 600°F., the lowest ignition temperature for JP-4 obtained with the engine. While the wheel cools to safe temperatures, it is shrouded with steam that prevents ignition. Once the water is discharged, in 4 seconds, the surface of the wheel reheats above safe temperatures by conduction from the hot wheel interior. A secondary water flow of ½ gallon spread over 30 seconds prevents this reheat and gives the safe cooling curve (dashed).

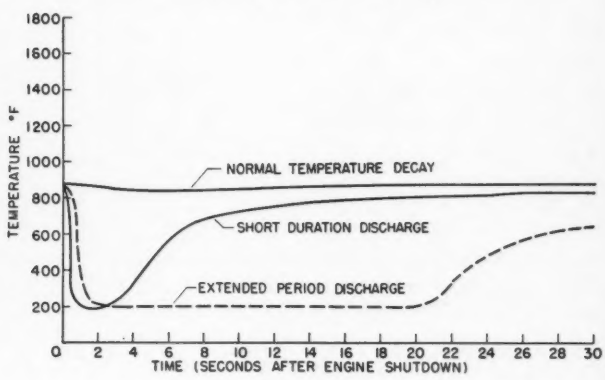


Figure 7.
Effect of water cooling on turbine wheel temperature

PROVING THE SYSTEM

In crash study of this use of water for preventing crash fire, the water is carried under gas pressure and discharged at the moment of crash impact. The complete crash-fire safety system (shown schematically in Figure 8) also includes the combustor fuel shut-off mentioned earlier and an electrical system disconnect for cutting off the battery and generator circuits, when crash occurs. Earlier work with reciprocating-engine aircraft showed the need for this disconnect to avoid hot wires and electric arcs that can ignite the airplane combustibles.

In six crashes in which this protection system was used, no fire occurred. Four of these airplanes were cargo airplanes with pylon-mounted jet engines, and two were F-84 airplanes with engines submerged in the fuselage. Four of these six crashes were of special interest.

In the first of these crashes a cargo airplane with pod-mounted jet engines carrying the protection system just described, ground-looped after passing through the crash barrier and was heavily damaged. Upon impact with the crash barrier, the airplane lost a wing, and fuel mist developed rapidly. Then the airplane ground-looped. Water vapor poured from the tail pipe as a result of water evaporation within the engine. Fuselage collapse brought the high wing and its engine to ground level, and fuel spilling from the wing poured over the engine. A pool of fuel observed at the engine inlet lips after the engine rotation stopped was part of the fuel that entered the engine after crash.

The engine bearing on the ground suggested the possibility that pylon-mounted engines might tear free in crash. For this reason, arrangements were made in the next crash to rip the engine from the wing. The water reservoirs of the protection system were fastened to the engine to provide fire protection after engine separation from the wing. In crash, the engine tore free and tumbled in the fuel mist spreading behind the wing. A water cloud issuing from the tail pipe indicated that the protection system was functioning. No fire occurred.

The crash-fire inerting system for the F-84 engines submerged in the fuselage was a little different from the system for the pod nacelles. In order to ensure entry of the fuel into the engine inlet when this airplane crashed, a bar fastened to the nose gear pointed at the wall of the 150 gallon fuselage fuel tank at the engine inlet. Upon crash impact, the bar attached to the nose gear pierced the fuel tank wall and released the fuel into the engine inlet. In the crash, the airplane carried a full load of JP-4 fuel and was protected like the cargo airplanes. The crash arrangements were about the same for the F-84's as for the cargo airplanes. The fuel mist from the broken wing tanks shrouded the area. Some vapor seen emerging from the tail pipe was provided by the fuel that passed through the engine from the damaged inlet tanks, and water evaporating within the engine contributed a large part of the vapors formed. Inspection of the engine taken from the airplane after crash showed the tell-tale dye stains left by the red-dyed fuel in the compressor.

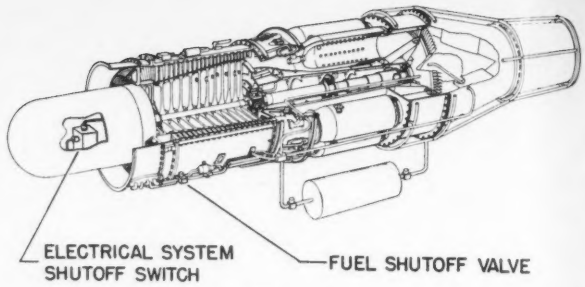


Figure 8.

Crash-fire inerting system

To check whether or not fire would occur if no protection were provided, this crash was repeated without the inerting system. A succession of flames issued from the tail pipe after the airplane struck the ground beyond the barrier.

A second crash of the F-84 airplane with protection system indicated again that the system is effective. Complete wetting of the airplane by the red-dyed fuel was observed.

These crash results with protected aircraft confirm the fact that the ignition sources within the engine that appear in crash were identified in the engine test-stand studies. These results also show that the use of water as described is one way of inerting these ignition zones.

OTHER IGNITION SOURCES

Engine Disintegration

Since there appears to be no way to cope with the fire hazard created by hot parts shed when an engine breaks up in a crash, no study of this phase of the problem will be made. It is recognized without further study that fire is likely should some of the engine parts scatter by a disintegrating engine land in fuel-wetted zones around the crashed airplane. Some comfort may be drawn from the fact that, although the engine struck the ground a hard blow in five of the above crashes, the hot parts of the engine remained in place.

Engine Deposits

Engine deposits are hazardous if they are large enough to provide zones of reduced gas velocity in their wake where crash-spilled fuel sucked into the engine may ignite readily. Large incandescent flakes of these deposits may be jarred loose in a crash. Upon discharge from the engine, they may ignite spilled combustibles. Further study of this type of engine-generated ignition source is needed. This problem may become important if slurry fuels are used for jet engines. These fuels, containing powdered metal, tend to leave larger deposits (metal oxide ash) than do the liquid fuels, which leave carbon deposits.

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C.A.I. LOG

SECRETARY'S LETTER

INTERNATIONAL MEETING

THE International Meeting has, of course, been the outstanding event of the month and a great deal of Headquarters' time has been spent on the final preparations for it and, later, on the mopping-up operations. It is surprising how much time is claimed by such little things as collecting an I.A.S. banner from Customs and mailing it back to the I.A.S. afterwards.

Undoubtedly the Meeting went well, and its success was due in no small measure to the excellent work of a group of members of the Ottawa Branch and to the enthusiastic help which we received from our three Ottawa Sustaining Members, Spartan Air Services, Computing Devices of Canada and Data Processing Associates. Such active participation by Sustaining Members is most gratifying and displays a real interest in the Institute. I could tell several tales to illustrate how unselfishly this help was given; as indeed similar help was given by our Sustaining Members in Toronto last May and in Montreal a year ago.

As usually happens on these occasions, I was unable to hear very much of any of the technical sessions but the Meeting did give me the opportunity to discuss a host of C.A.I. administrative matters with members from far and wide, and to get a great deal of valuable advice from visiting members of the I.A.S. Executive. In the latter connection I must mention how much I missed Mr. Dexter, Secretary of the I.A.S., who was nursing an injured leg in New York and could not be with us at this Meeting; these joint I.A.S./C.A.I. meetings were largely his idea.

PUBLICATIONS MEETING

On the morning of the 2nd November, the day before the International Meeting, a meeting was held between the Publications Committee and such members of the Editorial Board who could be in Ottawa at the time – we hoped to take advantage of the attraction offered by the big meeting on the following day. About ten members of the Editorial Board were there. This was the first meeting between the Publications Committee and any substantial number of the Editorial Board members, and it resulted in a most useful exchange of views.

For some time the Publications Committee has been uneasy about the scope and variety of the technical articles appearing in the Journal; they have felt that there was perhaps a preponderance of the highly mathematical papers and a dearth of good papers on more mundane engineering topics. This point, therefore, was discussed at some length. Before the meeting S/L McLeish had been through our membership records to determine the distribution of our members' interests and he reported an almost 50/50 balance between what might be called the theoretical and the practical categories. This was a tedious analysis but its results should give us valuable guidance in the future selection of papers. The problem now is to get people to write them.

(Incidentally in the course of this discussion, I was amused to hear the Structures experts claiming that the Aerodynamicists had been getting an unfair share of publication; to most of us there is not much to choose between them, when it comes to mathematics.)

SEASON'S GREETINGS

Since this is the last Secretary's Letter I shall write in 1955, I take the occasion to wish all our members and friends a Happy Christmas and all they wish themselves in the New Year.



INTERNATIONAL MEETING
I.A.S./C.A.I.



Mr. W. A. Shrader welcoming the members on behalf of the I.A.S. at the opening of the first Session. Mr. J. L. Orr (right) had previously extended a welcome on behalf of the C.A.I.

THE second International Meeting of C.A.I. and I.A.S. was held in the Chateau Laurier, Ottawa, on the 3rd and 4th November 1955. The registration for the technical sessions amounted to 424, and 711 members and guests attended the Dinner.

OPENING

The meeting was opened by Mr. J. L. Orr, Chairman of the Ottawa Branch of the C.A.I. who, at the beginning of the first morning session welcomed the visitors from the U.S.A. and members from other Branches of the C.A.I. This was followed by a brief introductory speech by Mr. W. A. Shrader, Director of Publications of the I.A.S., and the senior member of the I.A.S. staff present at the time – Mr. S. Paul Johnston, Director of the I.A.S., arrived later in the day. Mr. Shrader mentioned the extensive interchange of ideas between the R.C.A.F. and the U.S.A.F. and said that it was altogether proper that this interchange should extend into the technical fields as well as into the military.

The various technical sessions which followed are reviewed below.

LADIES PROGRAMME

A programme of entertainment and sightseeing was arranged by a C.A.I. Ladies Committee for the ladies of members attending the meeting. On the Thursday, lunch at the Green Valley Restaurant was followed by a bus tour of Ottawa and district, and on the Friday, the ladies were taken to the Supreme Court and Parliament Buildings. About 25 ladies took part.

THE DINNER

In the evening of the 3rd November a Dinner was held under the Chairmanship of Mr. R. D. Richmond, President of the C.A.I. The I.A.S. was officially represented by Dr. E. R. Sharp, their senior Vice-President. The Principal Speaker was the Rt. Hon. C. D. Howe, who was introduced by Mr. Richmond and thanked at the conclusion of his address by Admiral L. B. Richardson, a Past President of the I.A.S.

In his speech Mr. Richmond outlined the origins of the International Meeting and paid tribute to the I.A.S. for their encouragement and support in the establishment of this meeting as a major feature of the C.A.I.'s annual programme. He also mentioned the W. Rupert Turnbull Lecture, which had been presented for the first time at this meeting. He commended Mr. J. H. Parkin for the "meticulous and memorable address" which he had given. Mr. D. O. Turnbull, a son of the late Dr. Turnbull was also present at the Dinner and Mr. Richmond thanked him and the members of his family for their co-operation in establishing the Lecture.

In referring to the Ladies Programme, Mr. Richmond said that from the long experience and wisdom of the R.Ae.S. he had learned that it was important that the ladies should be present at an affair of this kind; not only were they decorative but they kept the men from too much "hangar flying" into the small hours.



Admiral L. B. Richardson thanking the Principal Speaker, the Rt. Hon. C. D. Howe.

He then read a cable received from the Royal Aeronautical Society as follows:

"The President and Council of the Royal Aeronautical Society send their cordial greetings on the occasion of the Second Joint Conference between the Canadian Aeronautical Institute and the Institute of the Aeronautical



Mr. R. D. Richmond, President C.A.I., speaking at the Dinner.



Dr. E. R. Sharp, Vice-President I.A.S., speaking at the Dinner.

Sciences and wish you all success in your deliberations."

In conclusion Mr. Richmond expressed the appreciation of the Institute for the honour recently conferred upon it by the Duke of Edinburgh in consenting to become its Patron, and he read the letter, just received from the Duke's Equerry, Lieut.-General Sir Frederick Browning, which is reproduced on page 200 of this issue.

Dr. Sharp spoke of the value of international meetings and, quoting Mr. N. E. Rowe, President of the R.Ae.S., he emphasized that their virtue lay as much in the contacts and personal friendships made between the technical men of the participating countries, as in the formal exchange of information in the presentation and discussion of technical papers. Less seriously, he endorsed Mr. Richmond's comments about the presence of ladies and finally told a never-to-be-forgotten story illustrating the difference between "exasperation" and "frustration".

The Principal Speaker, Mr. Howe, gave what he referred to as "a few reminiscences" of the development and expansion of Canadian airlines, particularly Canadian Pacific Air Lines and Trans-Canada Air Lines. His intimate association with them enabled him to give a remarkably detailed account of their early problems and more recent achievements.



Structures Session: (l to r) Mr. S. Bernstein, Mr. B. J. Kaganov (Chairman), Dr. N. J. Hoff and Mr. F. P. Mitchell.

TECHNICAL SESSIONS

The technical programme consisted of three technical sessions, two of them running concurrently, the delivery of the first W. Rupert Turnbull Lecture, and an inspection tour of the Montreal Road facilities of the National Aeronautical Establishment. These are reported on as follows:

Morning Session, November 3rd

Structures

Reported by F. R. Thurston

The Structures session was chaired by Mr. B. J. Kaganov and consisted of papers on supersonic aircraft design problems, a laboratory investigation of some aspects of the kinetic heating problem and the design of wing box beams.

The first paper was presented by Mr. F. P. Mitchell (Avro Aircraft Limited) and was entitled "Unique Structural Problems in Supersonic Aircraft Design". This paper represented a broad survey of the major structural problems involved in the design of supersonic aircraft with particular emphasis on the provision of rational analysis.

Dealing with the load analysis of very thin, low aspect ratio wings in conjunction with a flexible fuselage, Mr. Mitchell briefly described an analytic procedure in which the wing was treated as a plate and the problem set up in matrix form for the direct calculation of stresses by means of a high speed digital computor. It was found necessary to complement the method with conventional and more approximate analytic procedures.

The problem of fuselage frame stresses induced by the flexure and torsion of the wing was dealt with by an iteration procedure in which the best combination of low frame stiffness and high allowable static loads was sought. The control of stiffness and distorted form assumed a significance comparable with structural strength.

Without overemphasizing the importance of fatigue as a problem of fighter aircraft design, the author stated his conviction that early and continued fatigue testing of components was a major requirement.

The design of the landing gear was based on a method for calculating the dynamic response of the coupled gear-wing structures from frequency equations involving six degrees of freedom and design parameters were altered to obtain optimum dynamic characteristics.

The problems of aerodynamic heating were considered under three headings: the strength of materials at elevated temperature, induced stress and distortion due to transient temperatures, and creep.

In conclusion, Mr. Mitchell called for new and better structural alloys to match the exacting requirements of supersonic aircraft design.

The Chairman thanked Mr. Mitchell and questions from the floor were chiefly concerned with the statistics and relevant load levels for component fatigue testing, problems involved in the use of castings or forgings and the effects of elevated temperature service.

The second paper was to some extent complementary to the first paper in that it described laboratory investigations, proceeding in the Polytechnic Institute of Brooklyn, designed to afford an understanding of the fundamentals of structure behaviour at elevated temperatures. The paper was on "Experiment and Theory in the Investigation of the Behaviour of Structures at High Temperatures" and was presented by Professor N. J. Hoff.

The experimental work was introduced with a brief reference to established creep testing methods leading to the author's conviction that it was necessary to obtain experimental results on the creep of members in bending. A test rig for this purpose was described and other test rigs had been built to provide values of the exponent in the relationship between strain rate and stress and to obtain the ratio of the creep rates in bending and in torsion.

The effect of creep on the stress distribution in statically indeterminate structures was investigated and it was shown that, for certain simple types of indeterminate framework, satisfactory agreement had been obtained between

experimental results and the predictions of the theory of an elastic analogue. The analogue states that the stress distribution in a body whose deformations are entirely described by the exponential relation between stress and strain rate is the same as that in a body whose material is perfectly, but not necessarily linearly, elastic.

Creep buckling was another important phenomenon investigated experimentally at P. I. B. and rigs had been built for column testing and for testing circular cylindrical shells in flexure. Quantitative comparison of theory and experiment was incomplete.

The author completed a most interesting paper with descriptions of equipment for studying thermal stresses by means of induction heating and with an account of the problem of thermal buckling.

The Chairman thanked Professor Hoff and invited discussion of the paper. Questions were raised concerning instrumentation used in the P. I. B. experiments and it was intimated that no strain gauges were used on hot specimens to determine the stress distribution during the course of structural creep.

The third and last paper of the morning session was presented by Mr. S. Bernstein (Canadair Limited) on "Optimum Structural Design of Wing Box Beams".

The paper analysed the following types of construction used for compression covers on wing box beams: 1) Skin and Z-section stringers, 2) Double skin and corrugation panels, and 3) Solid plate multi-web construction. Curves of maximum compressive stress against the "structural index" were calculated and design charts were derived in each case to help select the most efficient rib or web spacing as well as the actual dimensions of the panel elements.

In addition, the structural efficiencies of the above types of construction were compared on the basis of: 1) Applied bending moment per inch width of structural chord, 2) Depth of the box beam and 3) Minimum skin thickness required for torsional rigidity.

Results were shown to indicate that over the range of variables considered the double skin corrugation form of panel construction was the most efficient except for the cases of very thin wings or low loading. For thin wings where the covers are primarily designed by stiffness requirements the solid plate multi-cell form was shown to be preferable, while at very low loading the skin-stringer panels were practically equal to the double skin corrugation panels.

Illustrative examples of the use of the method of analysis were presented for four categories of aircraft and it was shown how practical considerations may influence the choice of construction.

At the termination of this paper, the Chairman thanked the speakers for what had clearly been three very well-prepared papers on three most interesting subjects by three well-informed men.



Mr. J. H. Parkin delivering the W. Rupert Turnbull Lecture.

Afternoon Session, November 3rd
W. Rupert Turnbull Memorial Lecture

Reported by G/C H. R. Foottit

The afternoon session (November 3, 1955) was devoted to the W. Rupert Turnbull Memorial Lecture. This is a new annual lecture series to honour this distinguished, but little known, Canadian aeronautical engineer and scientist. The meeting was opened by the Chairman, Mr. T. E. Stephenson of the Department of Defence Production. In introducing the speaker, Mr. J. H. Parkin, Director of the Mechanical Engineering Division of the National Research Council, and Director of the National Aeronautical Establishment, the Chairman noted that the speaker had devoted most of his life to the aeronautical sciences in Canada. He was therefore well qualified to introduce this new lecture series, and set the stage for future lectures.

Mr. Parkin then took the stand. His subject was "Wallace Rupert Turnbull, 1870 to 1954: Canadian Pioneer of Scientific Aviation."

After graduating from Cornell University, in 1897 Mr. Turnbull took a position with what is now the General Electric Company in the U.S.A. Poor health, however, dogged Turnbull's early days. For this reason he left G.E. in 1901 and returned to his home town of Rothesay, N.B. Regaining his health, he set himself up as a consulting engineer, and opened up a laboratory in a nearby barn.

About 1900 he had taken an avid interest in the infant science of aviation. It was not surprising, therefore, that his earliest experiments were along this line. In 1902 he built one of the first known wind tunnels in the world, and used it to test numerous aerofoil sections. A few years later he became interested in propellers. He was one of the first to employ a carriage on a track, to assemble design data on propellers in forward motion.

With the outbreak of World War I Turnbull went to England and joined the firm of Fredrick Sage & Co. Here his inventive genius took root. He designed several aircraft propellers for the company, and got the idea for the variable pitch propeller, his greatest aeronautical invention. He also worked on aero engine improvements, hydroplanes, a torpedo screen to protect warships, a bomb sight, and other products of his fertile imagination.

He returned to Canada and his laboratory in Rothesay at the end of the war. He immediately set about perfecting his variable pitch propeller idea. After numerous failures, he finally produced a successful propeller that the R.C.A.F. tested in 1927. Two years later he licensed his design to a subsidiary of the Curtiss Wright Corporation. Thousands of propellers were produced under Turnbull's patents and license by the Curtiss company until the U.S. government purchased the license outright in 1944. The remainder of Turnbull's life was devoted to continued experiments along many lines, including a study for a tidal electric power station which is considered a model of ingenuity even today.

At the close of the lecture, Professor T. Loudon thanked Mr. Parkin for his excellent talk, and presented him with a certificate and honorarium to commemorate the occasion. Following this, the Chairman called on Mr. Donald O. Turnbull, Turnbull's son, who added some interesting anecdotes on his father's life. He was followed by Mr. George Parker, of Canadair, who had the honour of working with Mr. Turnbull when they were both with the Fredrick Sage company during World War I. The lecture closed with a few words from Mr. Harold H. Warden, Sales Manager for the Curtiss Wright Corporation, who spoke on the Wright controllable pitch propeller that had grown out of Turnbull's original propeller patents.



Aircraft Safety Design and Accidents Session: (l to r) G/C R. C. Davis, Mr. I. A. Gray (Chairman), Mr. I. I. Pinkel and Mr. J. Lederer.

Morning Session, November 4th
Aircraft Safety Design and Accidents

Reported by L. M. Nesbitt

This session, which was chaired by Mr. Ian A. Gray of Canadian Pacific Air Lines, included papers on general air safety, accident investigation and crash research. Before introducing the first speaker the Chairman explained that the customary question periods at the conclusion of the first and second papers would be dispensed with in order to give the author of the third paper time to present some interesting films, not previously shown to the public, of a recent N.A.C.A. crash research project. A general discussion of all three papers would be held at the end of the session if time permitted.

The Chairman then introduced Mr. Jerome Lederer, managing director of the Flight Safety Foundation, who presented a paper entitled "Significant Problems in Air Safety" in which he outlined the most significant problems facing civil aviation now and in the immediate future. One major problem is that of providing improved air traffic control to cope with the rapid increase in the volume of air traffic and the higher speeds and operating altitudes of turbine-engined aircraft. The greatest disaster that could befall civil aviation would be a mid-air collision between two scheduled air transports. Unfortunately the potential is there; it is estimated that an average of four near misses occur over the United States every day. At this point, Mr. Lederer showed a film of air traffic in the New York area in bad weather conditions as it would appear on a radar screen if the motion were speeded up 160 times. The speaker thought the situation would be alleviated by the use of ground radar control in all congested areas and by the development of an airborne proximity indicator.

Fatigue in aircraft structures is the "cancer of aviation". To cope with this problem American designers favor redundant structures and multiple stress paths. Pressure fuselages must be designed with adequate tear resistance to guard against explosive decompression resulting from fatigue cracks or other hidden damage.

A large proportion of accidents occur as the result of turbulence or during approach and landing in conditions of poor visibility. The introduction of storm warning radar and the Calvert centerline system of approach lighting is expected to make a significant contribution to safety.

Lessons learned from the investigation of aircraft accidents were set forth in the second paper entitled "Aircraft Accident Investigation" which was presented by Group Captain R. C. Davis, Director of Flight Safety, R.C.A.F. Giving as examples a number of accidents which he had investigated, the speaker showed how these could have been avoided by applying four precepts for aircraft design, viz.:

1) Procedure for adequate maintenance and operating practices established by designers should be consistent with average human effort, ability and attitude.
2) The aircraft and its components must be protected against the effects of normally inadvertent or uncontrollable human errors or carelessness.
3) Structures and mechanism must be designed to function safely and dependably over long periods of repeated use.
4) Parts or components of the aircraft other than basic structure should be designed to fail safe. This means that failure will not create additional or cumulative hazards.

The speaker concluded by emphasizing that once an error has been discovered and a fix established it should never be allowed to reappear in any later designs.

The third paper was given by Mr. I. Irving Pinkel, Associate Chief of the Physics Division, Lewis Flight Propulsion Laboratory, Cleveland, Ohio, his subject being "Crash-Fire Research with Jet Aircraft". He outlined some of the latest work being done by the N.A.C.A. to determine and alleviate the hazards of crash-fires and illustrated his talk by showing films of jet aircraft crashing through a crash barrier and catching fire. Slow motion pictures showed clearly how crash-spilled combustibles can be sucked into the engine inlet with air as a result of the continued rotation of the engine after the fuel flow to the combustors has been shut off. This combustible mixture ignites explosively on the hot metal of the engine interior causing flames to issue from the engine inlet and tailpipes which set fire to the fuel spilling from the tanks. Research into the mechanics of ignition inside the engine revealed that, owing to the high gas velocity through the engine, the combustible mixture has insufficient contact time with the bulk of the hot metal surfaces for ignition to occur. There are only four points inside the engine where the temperature is high enough and the contact time long enough to ignite the mixture. As a result of these studies, a crash-operated water inerting system has been developed which inerts these ignition zones at the moment of impact by spraying water over them. This system has proved to be very effective in preventing crash-fires with jet aircraft.

Leaving the subject of crash-fire research, Mr. Pinkel went on to describe, with aid of films, a recent N.A.C.A. research aimed at fixing the limits of survivability by simulating crashes such as occur when aircraft are flown into the ground at various angles. A survivable accident was defined as one in which the cockpit or cabin does not collapse in a way that precludes survival or makes it very improbable. Accelera-

tions experienced by the occupants were measured by accelerometers attached to anthropomorphic models. Films taken by cameras mounted inside the aircraft allowed the audience to ride with the dummies and watch their movements during the crash. These researches have led to the development of an experimental passenger seat with greatly improved energy absorption characteristics. Mr. Pinkel concluded his lecture with a film showing how this seat would make it possible for the occupant to survive a severe crash without injury.

Unfortunately, time did not permit discussion of any of the papers given at this session.

Morning Session, November 4th
Materials and Processes

Reported by W. Symmons

The other morning session was devoted to Materials and Processes under the able direction of the Chairman, Mr. H. L. Eberts.

The attendance was not good; due no doubt, to the more dramatic appeal of "Aircraft Safety Design and Accidents" lectures. However, if the materials and processes used in aircraft structures are right, there are less accidents due to structural failures; and, therefore, choice of which session to attend may have been difficult.

The first paper "Aluminum Alloys for Elevated Temperature Service" was presented by Mr. F. M. Howell, Chief of the Mechanical Testing Division, Aluminum Research Laboratories, Aluminum Company of America. Unfortunately, Mr. E. H. Dix, Junior, Assistant Director of Research, Aluminum Company of America, the author, was unable to present his paper because of sudden illness in his family. Mr. Howell was, therefore, called upon at short notice to read the paper on his behalf.

An interesting case for the continued use of present and future aluminum alloys at elevated temperatures due to aerodynamic heating was given in great detail, and an appeal made for the guidance of the aircraft industry.

The most advanced development in Aluminum Powder Metallurgy products is the Aluminum Oxide ingredient – and it appears to have great promise.

The second paper presented by Mr. Jason J. Waller, Chief Materials and Process Engineer, Canadair Limited, was entitled "The Metal Bonding of Assemblies for the CL-28 Maritime Reconnaissance Airplane".

This paper – delivered in very full detail but with an admirable economy of words – was most interesting, particularly in light of the ever-increasing use of the bonding process, even in such vital structures as helicopter rotor blades.



Materials and Processes Session: (l to r) Mr. J. J. Waller, Mr. N. E. Wahl, Mr. H. L. Eberts (Chairman), and Mr. F. M. Howell.

The saving of 1,000 pounds in structural weight, together with cleaner aerodynamic surfaces and increased fatigue life, are impressive considerations both to designer and operator.

Mr. Waller's lucid explanation of the role played in a good bond by polar molecules undoubtedly impressed his audience.

The paper was well illustrated with projected slides, and should be an excellent reference work for all engaged in this type of construction, its quality control and inspection.

The third paper presented by Mr. Norman E. Wahl, Head, Plastics Section, Materials Department, Cornell Aeronautical Laboratory, had for its title "Materials and Fabrication Techniques for Structural Heat-Resistant Plastic Sandwiches."

Mr. Wahl's subject and the problems being encountered in the quest to overcome the shortcomings of light-weight materials is of immediate interest to aircraft designers – particularly in the application of reinforced plastics to radomes.

Cornell Aeronautical Laboratory undertook the development of a core material to replace balsa and glass-fabric honeycomb. The objective to be gained in order to achieve the target as a whole constituted a formidable list of items, as follows:

(1) Low density.
(2) Good mechanical properties.
(3) Good electrical properties.
(4) Adhesion.
(5) Uniform structure.
(6) Ease of handling: easily processed.

None of the commercial resins available would produce a foamed-in-place core that even approached the target objective, and much work ensued to produce a suitable material.

Eventually, the development proved successful; and glass reinforced plastic radomes with foamed-in-place core material are now in general use for military aircraft.

Mr. Wahl completed his lecture with a short, but illustrative account of the work currently proceeding at Cornell – to explore the feasibility of designing and fabricating a light-weight, high strength missile wing of sandwich construction. If successful, we hope that the design will be used for budget-priced, personal light aircraft–just a little faster than the traffic cop's helicopter.

Afternoon of November 4th
Inspection Tour

About 100 members and guests visited the Montreal Road Laboratories of the National Aeronautical Establishment for the concluding feature of the Meeting. On arrival at the Laboratories the visitors were welcomed by Mr. J. H. Parkin, Director of the N.A.E., and then divided into four groups and conducted round a circuit consisting of the High Speed Aero and Gas Dynamics Laboratory, the Hydraulic and Ship Laboratory, the Engine Laboratory and the

Structures Laboratory, each group starting at a different point in the circuit. The Hydraulics and Ship Laboratory, although not strictly a part of the N.A.E., was included in the programme to enable the visitors to see the model of the St. Lawrence Seaway, which was expected to be of special topical interest – as indeed it proved.

Unfortunately several of those present, particularly the visitors from the U.S.A., had to leave early to catch trains and aircraft to take them home. Thereafter the groups that remained, greatly reduced in numbers, tended to break up, as individuals drifted off to examine more closely the work in which their respective interests lay; this was perhaps the most useful part of the tour for those who could take advantage of it.

Members attending the Meeting were fortunate in having this opportunity to examine the Laboratories and the work upon which they are engaged.

Copies of Pre-prints of the papers given at this meeting, other than the W. Rupert Turnbull Lecture, can be procured from

The Institute of the
Aeronautical Sciences
2 East 64th Street
New York

A few copies of a list of those who registered at the meeting are available from the Secretary on request.

ANNUAL GENERAL MEETING

The Annual General Meeting of the Institute

will be held in the

SHERATON-MOUNT ROYAL HOTEL

MONTREAL

on the

3rd and 4th May, 1956

The Programme, which will include Sessions on

Propulsion, Manufacturing, Design, Maintenance, Aerodynamics

as well as the annual Business Meeting,

is now being prepared.

This meeting affords an opportunity for the presentation of papers by members of the C.A.I. The Council is most anxious to encourage Canadian papers and hopes that any member wishing to contribute to any of the above-mentioned Sessions, will submit a summary of his paper for consideration. Such summaries must be in the hands of the Secretary by the 31st January 1956.

BRANCHES

BRANCH SECRETARY

Winnipeg

Mr. R. T. Gibson has had to relinquish the post of Secretary to the Winnipeg Branch. He has been succeeded by Mr. N. D. Brewer of MacDonald Bros. Aircraft. The new Secretary's address is

Mr. N. D. Brewer
525 – 2265 Portage Avenue,
WINNIPEG 12, Man.

NEWS

Winnipeg—Reported by R. T. Gibson

October Meeting.

The Winnipeg Branch of the Canadian Aeronautical Institute was fortunate in having as guest speaker for its October 25th meeting Mr. C. H. Glenn, Project Engineer (Evaluation), T.C.A., who chose as his subject "Aircraft Selection from an Airline Point of View".

The meeting was attended by approximately seventy-five members and visitors. The guest speaker was introduced by Mr. W. S. Haggett, Branch Chairman, who in his introductory remarks welcomed a distinguished visitor, the Honourable J. A. D. McCurdy.

Mr. Glenn prefaced his remarks with the comment that the selection of new aircraft is dictated by the major stockholders of some airlines, by the presidents of others, and by governments when state-owned airlines are concerned. He chose to speak of selections made on the basis of sound engineering and economic investigations.

Mr. Glenn stressed the extent to which the reliability of both the airframe and engine manufacturer must be checked. What are their financial positions; their research, tooling and manufacturing facilities? Have they capable and adequate design teams? What are their past records?

A design's future development must be considered. Is it basically an old aircraft, or is it new, with stretch possibilities? The proposed design must be closely examined. The structural and aerodynamic qualities, the systems designs, cockpit and cabin layout, crew size – all are scrutinized. Accessibility for easy maintenance and the ease of conversion for other duties are important items.

Having established that several new aircraft are wise engineering choices, their influence on the airline's financial statement must be considered. Mr. Glenn illustrated this phase of the investigation by selecting a hypothetical route and comparing costs of operation for two proposed aircraft – one powered by turboprops and one by turbojets – and a piston-engined one already in service.

Fleet size is dictated by aircraft size and speed and by the estimates of future traffic. If the latter prove to be seriously inaccurate, the resulting situation may be quite embarrassing. Utilizing detailed figures on depreciation, fuel, oil, insurance and maintenance expenses, crew salaries, and passenger service costs, the direct operating costs for each of the aircraft are established. Indirect costs are assumed equal to the direct costs. An estimate must be made of the fares which will be in effect when the new aircraft enter service. Considering all of this data, selection of the aircraft which will be most profitable is now possible. In the example used, the turbojet proved to be the money maker.

Following a lively question period, the meeting was adjourned when Mr. Haggett voiced the thanks of the members for Mr. Glenn's instructive and interesting address.

Montreal–Reported by E. Norsworthy

November Meeting

A small but very select group of members of the Montreal Branch C.A.I. attended the regular monthly meeting on November 16th at which the military approach and commercial approach to maintenance procedures for aircraft were discussed by Flight Lieutenant W. F. Delaney R.C.A.F. and Mr. Derek Bone of Trans-Canada Air Lines.

Flight Lieutenant Delaney in opening the discussion asked that his remarks be considered as representing his own opinions as a member of the Ottawa Branch C.A.I. and that they should not be considered as an expression of official R.C.A.F. policy. He went on to point out that the roles which military aircraft were required to fulfill embraced all the roles normally filled by a commercial aircraft plus the additional military roles of fighter interceptor, tactical support, strategic bombing, search and rescue, etc. This, of necessity, meant that types of aircraft in military use were more diverse than those in civilian use which in turn resulted in more diversity in their maintenance requirements.

Flight Lieutenant Delaney defined the four stages of R.C.A.F. maintenance as follows:

a) First Line, which consists of servicing, pre-flight inspections and minor repairs carried out by an operating flight or squadron.

b) Second Line, which consists of periodic inspections, relatively minor modifications, special inspections, replacement of some components and accessories and general line maintenance carried out by a support group of the operating unit or base.

c) Third Line, which consists of reconditioning and/or major repairs, incorporation of modifications and general maintenance carried out by R.C.A.F. repair depots and by civilian contractors both large and small.

d) Fourth Line, which consists of complete overhaul, major repairs, conversion of equipment and heavy maintenance carried out by a large civilian contractor, often the original manufacturer.

Flight Lieutenant Delaney mentioned that First and Fourth Line maintenance was well defined and well understood and thus required no particular comment. Second and Third Line maintenance were more complex and were presently in a state of flux. He pointed out that Second Line maintenance was essentially preventative maintenance and consisted of inspection of specified areas, systems and components at planned intervals, which in the R.C.A.F., were expressed in terms of flying hours. The R.A.F. had changed to some extent, to calendar cycles and this method was also under consideration by the R.C.A.F. He pointed out that the two most common difficulties in making up maintenance schedules were the combatting of

the "just in case" attitude and the possibility of too frequent maintenance operations producing an epidemic of "tinkeritis". The three main considerations were safety, operational efficiency and economy. Of the three, safety items allowed no compromise but the remaining two considerations gave much more leeway for individual interpretation depending on the type of aircraft use. For example, failure of an item affecting passenger or crew comfort could be completely unacceptable from a commercial viewpoint but might be tolerated from a military viewpoint. Conversely, the failure of an item of equipment e.g. radar or armament, could be serious from a military viewpoint without affecting the flying characteristics of the aircraft or comfort of the crew. A balance had to be struck between too little routine maintenance with the consequent penalty of a large number of non-routine defects and too much routine maintenance with the penalty of excessive costs in manpower, equipment, dollars and time. The speaker considered that reduction of the time required for maintenance was of equal importance to civilian and military operators since a military aircraft was required to be available for use as much as possible whether flying or not. He pointed out the importance of a complete and accurate system of records for establishing component lives so that any alteration could be made on the basis of actual experience.

Flight Lieutenant Delaney went on to describe the evolution of the I.R.A.N. (inspection and repair as necessary) concept in the U.S.A.F. and of the similar C.A.I.R. (calendar aircraft inspection and repair) concept in Canada. Under both these concepts, the aircraft is returned to a repair facility periodically and is reconditioned, using as a guide a manual which not only defines the inspection and the work but also establishes the criteria to be used in the inspection of the aircraft. These criteria are established on a "serviceable but not new" basis. Since this process is continuous and is based on a calendar cycle the return of aircraft to the facility is steady and orderly and permits logical advanced planning by both the Contractor and the Service. This concept also results in a reduction of maintenance time in the field since the aircraft is reconditioned p r i o r to the time where excessive expenditure of field maintenance man-hours becomes necessary to keep it serviceable. In summary, the C.A.I.R. concept eliminates the idea of a major overhaul when the aircraft is excessively worn and substitutes a series of less expensive reconditionings on a periodic basis.

Mr. Bone, in giving the commercial operator's viewpoint, commenced by describing the T.C.A. maintenance facilities and went on to outline the system of periodic checks used on their fleets. These consisted of five checks; Nos. 1 and 2 accomplished at 35 hours and 100 hours respectively consisting essentially of servicing and line maintenance, and Nos. 3, 4 and 5 accomplished at 500, 1,500 and 3,000 hours respectively, covering the major maintenance of the aircraft. He described the system of zone overhaul by which selected zones of the aircraft were overhauled progressively and concurrently with periodic checks and described how this method eliminated the necessity for a major overhaul of the aircraft with its consequent lengthy period when the aircraft was out of service. He pointed out that this system provided a continuous check on major structural items whereby serious defects could be detected sooner than in the conventional major overhaul procedure. He discussed T.C.A.'s maintenance operations in some detail showing how the work load at a major check was broken down into (a) periodic maintenance operations, (b) replacement of time-expired units of equipment, (c) incorporation of modifications and (d) the overhaul of specified zones.

Subsequent discussion during the question period led to an examination of the function of the licensed air engineer in the face of the increasing complexity and diversity of aircraft maintenance operations. It was suggested (and concurred in most enthusiastically by those present) that a panel discussion be arranged in the new year to discuss this question among representatives of the major operators, independent operators, manufacturers' inspection departments and representatives of the Department of Transport. It is hoped that it will be possible to arrange such a discussion in the not too distant future.

November Meeting

Toronto—Reported by M. D. Willer

The third meeting of the current season was held at the Royal Ontario Museum theatre on November 22nd last when the speaker was Mr. Franklin T. Kurt, Quality Control Manager for the Grumman Aircraft Engineering Corporation. Mr. Kurt took as his subject "Quality Control – Its place in aircraft design and manufacture".

The old concept of Inspection as a kind of police force finding the evidence after the deed was committed was obsolete and wasteful. Quality Control, by examining the many factors that could lead to the non-acceptability of components, could take remedial and preventive action to forestall this waste – to prevent the deed being committed.

The human side of manufacturing must not be overlooked. In some situations the efficiency of the plant cafeteria should be one of the first things Quality Control should check – the poor quality of the employees' food might well be matched in poor quality post-prandial production.

Quality Control should be employed at all stages of the manufacturing process and, whilst it should not try to usurp the time honoured prerogatives of Design, it should at least have one foot in the ivory tower. It might often prevent some very red necks above white collars.

The importance of Quality Control will grow, the speaker contended, as the field of guided missiles grows. The view that the quality of the aircraft was good enough if the darned thing landed safely could not be extended to this new field. The quality of a guided missile is not good enough if it does not hit the target. To ensure that it does hit the target every time a very high standard of accuracy must be maintained and to ensure this Quality Control will be essential.

One reason why Quality Control is so important in the aircraft industry is that the low volume output has such a high manhour content. This makes for an expensive product and rejections must be held to a minimum to hold costs down. In one sense, Quality Control is synonymous with Cost Control.

The aircraft industry, despite its size, is still a young and an immature industry. The early pioneers in the top echelons of management have a wide practical knowledge of all aspects of the industry. The trend to a narrow specialization in the lower echelons, though necessary, due to the increasing complexity of the product, sometimes leads to lack of effective liaison between departments. An effective Quality Control, watch dog of both aircraft safety and cost, would stand guard in the interest of more efficient production.

The address was followed by a questions period, in the answers to which the speaker made the following points.

1. U.S. top management is not yet 100% behind the new broad concept of Quality Control but is gradually elevating it in importance.
2. A major factor in acceptance by management is the growing realization that an effective Quality Control can forestall waste and reduce costs to a far greater degree than the old concept of Inspection.
3. Quality Control has not been forced upon the industry by the military consumer. Rather, it has grown during periods of curtailment since

World War II to reduce waste and raise productive efficiency.

4. How Quality Control would fit into aircraft development and experimental departments was an open question but there was a growing feeling that it should. Quality Control is growing – indeed, at one U.S. firm the production test pilot group is part of the Quality Control organization.
5. A good Quality Control man has to have something more than technical knowledge. He has to be an extrovert, to have a genuine liking for and to be able to deal with people.
6. Attempts to educate personnel in the principles and practice of Quality Control are being undertaken at all levels. A well conceived and intelligently publicized drive in its support will show results. Quality cannot be inspected into a product – it must be built in and the human beings who are responsible for building it in can be educated to realize their responsibility.

SUSTAINING MEMBERS

A. V. ROE CANADA LTD.

CONGRATULATIONS are due to A. V. Roe Canada Ltd. which recently celebrated its 10th birthday. On the 1st December 1945, Sir Roy Dobson took over the fading remnants of Victory Aircraft Ltd. and founded a company, which today is the A. V. Roe Canada Group, comprising Avro Aircraft Ltd., Orenda Engines Ltd., Canadian Steel Improvement Ltd., and Canadian Car and Foundry Company Ltd. The brilliant achievements of the group in these short ten years, notably the Jetliner, the Orenda and the CF-100, are an inspiration to everyone associated with Canadian aviation.

NEWS

Canadian Aviation Electronics Ltd. has recently set up a laboratory in the new Timmins Business Aviation hangar at Dorval Airport. With this laboratory, facilities for adjustment, repair and maintenance of all electronic equipment in visiting aircraft will become readily available, while more extensive work can be handled by the main C.A.E. plant situated not far away.

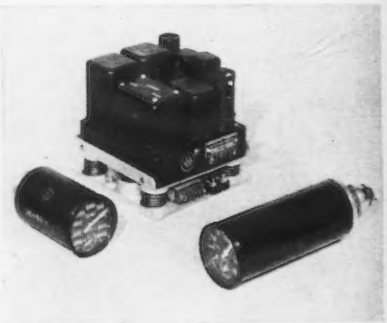
General Controls Co. (Canadian) Ltd. announces the development of the AL-58D series pressure switch for the control of pumps, warning lights and other aircraft systems. The new switch weighs less than 8 oz., is only 3½" long, and reacts to pressures ranging from 25 to 10,000 psi with a differential of about 10 per cent. The unit is sealed and can be used in systems handling corrosive fluids and a totally-enclosed model is designed for explosion-proof applications.

Minneapolis-Honeywell Regulator Co. Ltd. reports the development of a transistorized exhaust gas temperature indicator system having many advantages over the vacuum tube systems now available.

The new system is a hermetically sealed, single indicator-amplifier package. It weighs only .8 pounds and has a volume of 17 cubic inches. In contrast, comparable vacuum tube systems weigh 3.5 pounds and have a volume of 130 cubic inches. The new system does not require shock mounting. It may be mounted directly on the instrument panel.

It will indicate temperature range of 1000 degrees, i.e. 0-1000°C. or 200-1200°C., thus making the system adaptable to either turbo-jet or turbo-prop installations. Accuracy is ±5°C. for a minimum of 1000 hours without calibration. Indicators can be provided in either 2" or 3¼" dial diameters. The outstanding feature of the transistor system is its greatly improved reliability over vacuum tube counterparts. This is due not only to the inherently more rugged nature of the diode and transistor components but also to the manner in which circuits have been designed around them.

In operation, the chromel-alumel thermocouple circuit is brought into the package through the hermetically-sealed connector. It is terminated next to the cold-junction compensator, preventing uncompensated cold-junction error. The thermocouple signal is compared with a rebalancing potentiometer signal. The potentiometer is supplied with an extremely accurate reference voltage obtained from a silicon diode operated in its Zener voltage range. Changes in reference voltage due to ambient temperature and line voltage changes are completely compensated. Variations in the reference voltage do not exceed ±0.1% even under extreme conditions.



The Minneapolis-Honeywell transistorized exhaust gas temperature indicator is shown on the right, in comparison with the vacuum tube power unit and indicator which it replaces.

The error voltage between the thermocouple signal and the rebalance potentiometer signal is converted to a-c by a transitor modulator. The modulator gives transitor reliability and at the same time eliminates the need for electrical contacts common with d-c to a-c electromechanical choppers.

The a-c voltage is applied to the amplifier input by means of a transformer that matches impedence and also isolates the thermocouple input circuit from ground. The latter feature prevents accidental shorts to ground on either side of the thermocouple harness circuit from disturbing system calibrations.

The error signal is amplified by the transistor stages and is impressed upon a Honeywell power-type transistor in the output stage. The output stage discriminates between the relative phase of the line and error signal and drives the rebalance potentiometer to balance out the error signal by means of a miniaturized two-phase induction motor.



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